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# PROJECTED PROCESS ECONOMICS FOR ETHANOL PRODUCTION FROM CORN

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July 17, 1992

Final Report To:

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Work Done Under Agreement Number 58-1935-2-020

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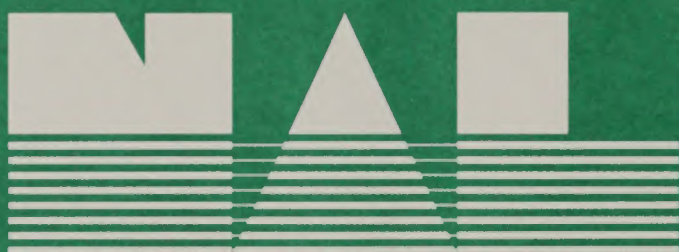
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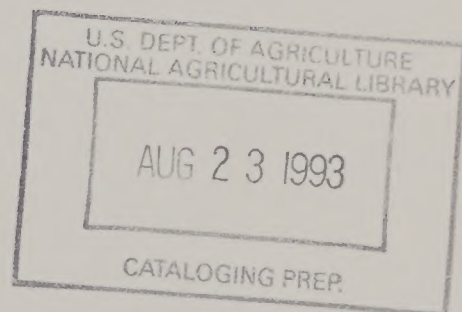
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## CHAPTER 1. REPORT SUMMARY

### INTRODUCTION

In order to identify technology which can reduce the cost of producing ethanol by fermentation using corn as the raw material, an engineering and economic analysis was completed on the design for the base case of a typical existing dry mill/ethanol plant and three alternatives. The criteria for choosing an alternative are that the essential concepts of the technology have been demonstrated at a pilot plant scale or larger and that it is likely to be implemented in the next 3 to 5 years. This focus avoids getting into many innovative ideas that are in the laboratory stage, where reliable mass and energy balances and capital and operating costs are unavailable or self-promoting.

The first alternative is the Biostil Process which was initially developed by Alfa-Laval in Sweden. The process has been acquired by Chematur of Sweden and is available in the U.S. from Weatherly, Inc. of Atlanta, Georgia. The process uses a single continuous fermentor with several on-line loops involving screens and centrifugal separators and mash column. The net result is a process that produces a stillage at about 30 wt% total solids at the bottom of the mash column. With the high total solids, there is no need for an evaporator and the high pressure steam to run the turbine for the vapor recompressor. Thus a cheaper low-pressure packaged boiler can be used. The process is used world-wide in cane molasses fermentation to ethanol. Also, two plants using wheat starch fermentation are in operation. It is an ideal concept to be applied to corn based fermentation.

The second alternative is a technology for dehydrating ethanol using corn grits as an adsorbent for the water. The process was developed by Professor Ladisch of Purdue University and is used by the ADM Corporation in their plants. It is the only known adsorption dehydration technology that is practiced above an ethanol plant capacity of 30 million gallons per year (a limit for the use of molecular sieves). The adsorption columns and regeneration loop equipment replace the conventional azeotropic solvent distillation and solvent recovery columns. Naturally, there is no need for have the solvent, such benzene, in the plant.

The third alternative is not so much a process alternative but a commentary of the role of fuels, boilers, cogeneration options and energy costs. There are trade-offs between capital cost and energy cost that change as fuel and electricity costs change.

A quick summary chart comparing the capital and operating costs of the process alternatives is given in Table 1.

### RESULTS

The base case is a typical plant using dry corn milling, jet cooking, enzymatic liquefaction and saccharification, batch fermentation, distillation and solvent dehydration. The stillage is



**TABLE 1. COMPARISION OF DESIGN ALTERNATIVES**

Corn based ethanol plant in Illinois, 1992  
 50 million gallons per year, 199° (99.5%wt%)  
 corn \$2.50/bu  
 DDGS \$120/ton  
 coal \$25/ton  
 natural gas \$1.50/Mbtu  
 electricity \$.05/KWH

<b>Design Alternatives</b>	<b>Fixed Capital</b>	<b>Annual Net Cost</b>	<b>Net Operating Cost, \$/gal</b>	<b>Annual Saving over Base Case</b>
1. Base Case	\$118,100,000	\$57,700,000	\$1.154	
2. Biostil	\$105,100,000	\$55,300,000	\$1.106	\$2,400,000
3. Corn Grits	\$113,600,000	\$57,200,000	\$1.144	\$500,000



separated into wet solids cake and thin stillage (solubles) by centrifugation. The thin stillage is evaporated from 6% to 7% dissolved solids to a syrup of 45% to 50% solids. Then the wet cake and syrup are mixed together with a recycle stream of dried DDSG to form friable particles that are dried in a rotary kiln. Detailed process descriptions, equipment lists, flowsheets and material and energy flows are given in Chapter 2.

In order to get at the capital and operating cost for the base case and a basis to evaluate the alternative processes, we had to get numbers that people generally consider confidential. Fortunately we had available a published report by Raphael Katzen Associates, AN493, December 31, 1978 to the Department of Energy entitled "Grain Motor Fuel Alcohol Technical and Economic Assessment Study. The design is for a capacity of 50 million gallons per year 199 proof ethanol located in Illinois. The flowsheets were introduced into our computer by an optical reader and then are available for reducing to a convenient size and modification for the alternative processes.

The purchase cost of the major equipment items in the plant design were brought up to 1992 costs by applying the Chemical Engineering Plant Cost Index (CEI). The technical and economic features of the base case were verified by plant visits to the major ethanol producers and telephone interviews with key engineers at various design houses.

Although the Katzen design used carbon steel for fermentors, tanks and columns, it is clear from the current practice that 304 SS should be used. Consequently we modified the cost of key carbon steel items to their corresponding items in 304 SS by applying a generally accepted factor of 2.2. This is important when comparing process alternatives that you have a common quality in the equipment material of construction and fabrication standards.

The total capital investment or fixed capital of the plant is developed from the delivered or purchased cost of the major equipment items in each section of the plant flow sheet. The plant has seven sections, namely, grain storage and handling (section 100), cooking and saccharification (section 200), fermentation (section 400), distillation and dehydration (section 500), feed processing (section 600), storage and shipping (section 700) and utilities (section 800). The flowsheets for each section are given in Drawings 345411-01 through 345411-13 and the equipment lists with the purchase cost for each section are given in Tables 2 through 8.

The final capital required for each section of the plant is estimated in Table 9 by the Chilton factors to account for the equipment installation, materials and labor, process piping, instrumentation, foundations, building and others such as insulation, painting, electrical service, process air, and lighting. Then the engineering and construction cost and contingencies are affixed.

The total investment of \$118,100,000 in Table 9 for the base case plant is in line with the rule of thumb that ethanol plants cost between 2 to 3 dollars per annual gallon of capacity. The largest section costs are \$37 million for the feed processing of DDGS, \$33 million for all the utilities and \$19 million for the fermentation.



The operating costs are given in Table 10 to account for materials, labor, energy, annual capital related costs and by product credits. The table gives the direct cost of production. The investment charges are taken as a straight line depreciation over nine years, the typical IRS approach for plants of this type. Thus each year 11.11% of the investment is charged off.

The net cost includes the credit for the sale of DDGS. However, this net cost does not include the interest on money, profit, general sales and front office administration expenses. These factors vary from plant to plant and are not relevant when comparing the economics of process alternatives at a given location. Just be aware that the net unit cost is not the selling price of the ethanol. The cost for corn at \$2.50/bushel, DDGS at \$120/ton, coal at \$25/ton and electricity at 5¢/kwh are typical of today's costs.

It is clear from the operating cost sheet, that the corn cost is the dominant cost at 62%. When the DDGS credit is applied the cost is reduced by 26%. Capital charges account for 21% and coal and electricity each are about 3% and labor costs with fringe benefits are about 7%. Without the DDGS, the cost of production is \$1.57/gal. As ethanol demand increases to double and triple of the current demand, the sales of the corresponding increasing amount of DDGS will saturate the feed market. In the long run the credit for DDGS will become less than it is now which will result in an increasing net cost of ethanol production. This means we need to consider other substrates and the technology for using them and/or new uses for DDGS.

Finally because the cost of production changes with material, energy and capital costs, a sensitivity table is provided in Table 11 to give the change in production cost for changes in the cost of corn, DDGS, coal and electricity. The capital cost is of course an estimate and so the impact of an increase or decrease in the estimated capital by 10% is also shown in the sensitivity table. Although Katzen claims a yield of 2.65, the yield of ethanol is typically 2.55 gal per bushel of corn. Since the theoretical maximum is 2.89 gal/bushel based on the starch conversion to ethanol, some improvement is possible and is worth 3.6¢/gal for every 0.1 gal/bushel increase.

The Biostil Process information comes to us from Weatherly, Inc. in Atlanta, Georgia. They provided a turnkey plant design. In order to be able to compare their process fairly with our base case, we needed to know more about the process. Consequently, we signed a non-disclosure agreement to get this information. To respect this agreement, we show the cost of the delivered equipment to each section as a whole without the detailed equipment size and cost of each item in the equipment lists. These equipment lists are included in Chapter 3.

In order to exploit the Biostil Process, it is possible to replace sections 200, 400 and 500 in the base case design with the corresponding sections provided by Weatherly which are shown in Drawings 345411-14 through 345411-17. While this approach will show the economic advantage of the Biostil process, it should be pointed out that even greater cost savings are possible if the entire plant is designed by the same design house such as Weatherly. This way, you can really get all the energy and material flows optimized. The equipment is generally 304 SS for process vessels and 316 SS for plate heat exchangers. The saccharification (section 200) is similar to the base case except enough hold-up tankage is provided to achieve complete



saccharification before going to the fermentor. In the batch fermentation process, one has 50 to 60 hours to allow saccharification to be completed in the fermentor. In the Biostil Process the holding time in the fermentor is less than a day so the starch should be completely hydrolyzed before fermentation. The fermentation section 400 has one large fermentor instead of 16 in the base case. The other major items in this section are bent screens to remove fiber from the yeast, centrifuges to recycle the yeast to the fermentor and other centrifuges to separate the fiber from recycle fluid. The distillation and dehydration section (500) has a specially designed mash column or stripping column. The fiber stream and the fiber free yeast free stream are stripped of alcohol in a two section stripping column. The enriched alcohol from the stripper is purified to 190 proof in a heat integrated rectification column. The dehydration is achieved by the standard solvent distillation with heat integration with the mash column. The bottoms of the mash column are about 30% total solids - ready for drying in any conventional DDGS dryer or flash drier.

The cost of the delivered equipment in sections 200, 400 and 500 (listed in Tables 12, 13 and 14) were supplied by Weatherly as a lump sum for each section. We used these costs as inputs to the same method as used in the base case to develop the fixed capital cost for the Biostil Process alternative (Table 10). Sections 100 and 200 are the same as in the base case. The equipment list (Table 15) for Section 600 is very much simplified because the thin stillage evaporator, vapor recompression equipment and centrifuges to separate the suspended solids from the soluble solids are all eliminated. Consequently, the fixed capital investment for Section 600 is reduced by \$24.7 million from the base case. The final impact of the Biostil Process is that the higher pressure boiler in the base case is replaced by a packaged boiler for generation of low pressure steam (Table 16). In order to take advantage of the relatively low price in natural gas, the fuel is changed from coal to natural gas. Again, comparing the fixed capital in Section 800-A for the base case and Biostil case shows a reduction of about \$12.1 million. Overall, the Biostil Process has a fixed capital of \$105,100,000 (Table 17). The impact of the capital investment and fuel change is given in Table 18 for the operating cost of the Biostil Process. The sensitivity to fuel and electricity costs in the Biostil is somewhat different from the base case since more energy is used in the Biostil case. These sensitivities are shown in Table 19. Corn and DDGS price sensitivities are the same as in the base case since the usage and yield are the same in all alternatives.

For the second alternative using corn grits to dehydrate the ethanol from the rectifying column, the approach was to keep all the sections of the base case as before except for section 500 which is given in Drawing 345411-18 in Chapter 4. The beer still has been redesigned to operate at atmospheric pressure rather than at 50 psi with 150 psi steam in the reboiler as in the base case. There is no dehydration distillation column to be operated through the heat coupling approach. Instead, the hot ethanol/water vapors are passed through a packed bed of corn grit where water is adsorbed. When breakthrough occurs, the flow is switched to another bed. The water saturated bed is regenerated with hot CO<sub>2</sub>. The water is condensed out of the CO<sub>2</sub> stream and the CO<sub>2</sub> is recompressed to pass through the regeneration loop again. The ethanol vapor leaving the corn grit bed now 199 proof is condensed and ready to mixing into gasoline. From the equipment list for Section 500 in Table 20, the capital reduction in is about \$4.5 million over the base case. The fixed capital, given in Table 21, for the entire plant is \$113,600,000. The



operating cost is given in Table 22. Because the electric load is higher for the corn grit process, due to operating the CO<sub>2</sub> blower, the electric cost has a different sensitivity on the cost of ethanol production over the base case (see Table 23). The other sensitivities are the same as in the base case.

The third alternative deals with the energy utilities. Since about 10¢/gal of ethanol can be attributed to coal costs and capital charges in the investment for the boiler, consideration of the fuel cost - capital investment trade-off in utilities is as important an area to reduce the cost of production as the fermentation distillation and drying process alternatives. A brief discussion in Chapter 5 is given on the issues to consider.



## CHAPTER 2. BASE CASE TECHNOLOGY

### PROCESS FLOWSHEETS AND DESCRIPTIONS

#### INTRODUCTION

Conceptual flowsheets were developed for a base case process and two process alternatives. The first alternative substitutes the Chematur Biostil continuous integrated fermentation and distillation. The second alternative uses an ethanol dehydration based on a corn grit sorbent.

The base case flowsheets, process descriptions and equipment lists presented here are from a report to the United States Department of Energy: Grain Motor Fuel Alcohol Technical and Economic Assessment Study by Raphael Katzen and Associates, Cincinnati, Ohio, Report No. AN 493, Dec. 31, 1978.

The Biostil alternative flowsheets and description presented here were developed from non-proprietary information provided by Weatherly, Inc., Atlanta, Georgia, as well as United States patent literature. Additional proprietary information was given to the authors by Weatherly, Inc. in order to be able to consider the new technology in a consistent and fair comparison with the base case.

The corn grit dehydration alternative flowsheets and description presented here were developed from United States patent literature and information provided by the Archer Daniels Midland Company.

The design basis for the plant is 50,000,000 gallons of 199 proof (99.5 wt. %) ethanol with around the clock operation for 330 days per year.

#### BASE CASE PROCESS FLOWSHEETS AND DESCRIPTION

The overall material and energy flows for the base case process are given in Drawings 345411-01 and 345411-02.

A unit-by-unit description of the process for manufacturing motor fuel grade alcohol from grain (corn) for the base case is given below. Conceptual flowsheets for each of the processing steps (Sections 100 through 800) are presented as Drawings 345411-03 through 345411-13.

##### Section 100 - Grain Receiving, Storage, and Milling

The process flow diagram for grain receiving, storage and milling, Section 100, of the base case plant is shown in drawing 345411-02.



Shelled corn is delivered to Section 100 by railroad hopper cars or grain trucks, a single railroad unloading station and two truck unloading stations have been provided. The unloading arrangement has been planned so that a railroad hopper car and a truck can be unloaded simultaneously. Unloading conveyors have been specified to accommodate a total unloading rate of 7,500 bushels/hr which would provide enough grain in a single 8-hour shift to operate the plant for a full day.

Trucks, delivering grain to the plant, are lifted by means of truck dump hoists and are weighed on one of the two Truck Dump Scales, SC-100A or B. The grain passes from the truck into a bin housed in a pit. Grain is discharged from these bins through star valves into either of two Truck Unloading Conveyors, C-101 A or B.

In the case of grain delivered to the plant by railroad hopper cars, the car is weighed on Rail Car Scale, SC-106, and the grain is the dumped from the car though a bin and star valve to Rail Car Unloading Conveyor, C-101C. The grain then passes into either of two Rail Car Unloading Cross Conveyors, C-101D or E. A truck unloading conveyor, coupled with a rail car unloading cross conveyor, can then be delivered into Bucket Elevator, BE-102A or B.

The grain is lifted to a position above the Grain Storage Bins, SB-104, A through D, and passes from the bucket elevator into one of two Distributing Conveyors, C-103A or B. These conveyors are arranged to deliver to the storage bins or may convey their grain directly into Storage By-pass Conveyors, C -130A or B, which deliver directly into Surge Hopper, H-118.

The surge hopper has been sized to hold 7,500 bushels of grain. This provides a nominal holdup time of three hours. When the surge hopper is full, grain can be diverted into storage in any of the grain storage bins. The total grain storage capacity is equivalent to grain usage for one week. When grain is being received, operation could have grain passing directly to the surge hopper. When it is filled, grain would then be diverted to the storage bins. When grain is not being received, grain would pass from the storage bins to the surge hopper through the individual Storage Bin Bottom Conveyor, C-110 through C-113, though Collecting Conveyor, C-114, and into Bucket Elevator, BE-117. The grain is thus lifted and discharged into the surge hopper.

Grain discharges from the surge hopper at the rate of 2,453 bushels/hr into Grain Cleaner, S-121. The grain cleaner separates materials in the grain which are foreign to the process, including such things as sand, tramp metal, etc. Light material in the grain are picked up from the screens and air transported through Blower, B-122, to the Bag House, BH,644, in Section 600 where they become part of the Distiller's Dark Grains (ddg) by-products, Tramp metal and other oversize materials are rejected from the grain cleaner and are periodically removed from a collecting bin.

Grain, which is suitable for processing, passes into the Hammer Mills, H-125 A through D. The hammer mills deliver into Surge Bin, SB-126. The ground grain the passes through a star valve at the base of the surge bin and is pneumatically conveyed to Mash Cooking and Saccharification, Section 200.



The grain receiving, storage, and milling area has been separated from other plant processing areas because of the dust problem associated with these front end operations.

### Section 200 - Mash Cooking and Saccharification

The cooking and saccharification section is shown on Drawing 345411-04. Corn meal is received from the milling area in the Surge Tank, TK-202. This tank is sized to allow continuous meal input while the output to the Batch Weigh Tank, TK-204, is shut off when the batch tank is being emptied into the Continuous Weigh Tank, TK-206. The batch weigh tank provides an accurate record of the total grain used, and the continuous weigh tank provides a reading of how much grain is used within any given time period. The continuous weigh tank feeds the Mash Mixing Tank, TK-209, where the other mashing ingredients are added. This tank is sized for a 2.5-minute residence time and is fitted with a agitator to promote thorough mixing. The other main ingredients are recycled thin stillage (backset), and water. The water comes from recycled condensates and from makeup fresh water. The condensates are hot, and their use is regulated to maintain a tank temperature of 145°F. The total water input to this tank is controlled to produce about 22 gallons of mash per bushel of grain input (56 lb/bushels basis). The thin stillage is added in an amount of about 10% of the final mash volume going to the fermentors.

The mash is transferred from the mixing tank to the Mash Pre-Cooker, TK-211. This tank has provisions for adding live steam in case insufficient condensate is available to attain the 145°F pre-cooking temperature. This tank is sized for a residence time of about 7 minutes.

The mash is further heated on the mash heater, E-229, located downstream of the pre-cooker. This heater uses 15 psig steam from the pressure flash to heat the mash to 229°F. Final cooking of the mash takes place in the mash cookers, PLR-214A and PLR-214B, by injection of live steam to attain a temperature of 350°F. The cookers consist of several 20 foot lengths of 10 inch diameter pipe connected with 180 degree return bends and they are sized to provide a cooking time of 1.5 minutes.

The cooked mash is flashed to 15 psig in the Pressure Flash Tanks, TK-215A and TK-215B. Some of the steam from the flash is used to preheat the mash as described above, and the remaining flash steam is used for beer heating in the distillation section. Additional water is added at this point in an amount to provide a final mash volume of 30 gallons per bushel. The mash is further flash cooled in the Vacuum Flash Tanks, TK-216A and TK-216B. The temperature leaving these tanks is 145°F which corresponds to a pressure of about 3.3 psia. This vacuum is maintained by the Flash Vapor Condenser, E-224, its associated Steam Ejector, EJ-225, and the Ejector Condenser, E-226. The condensate from all of these heaters and condensers goes back to the Hot Well, TK-227, from where it is pumped back to the mash mixing tank as discussed above.

After the vacuum flash, the mash discharges directly into the Amylase Mixers, MX-220A and MX-220B, where the amylase is added. From the mixer the mash is pumped to the Pipe Line Saccharifier, PLR-222, where the starch is converted to fermentable sugars.



The pipe line saccharifier is sized for a two minute residence time. From the saccharifier, the converted mash is fed through the Mash Coolers, E-223A through E-223J, to the fermentors in Section 400. The first six mash coolers use cooling tower water at 85°F to reduce the mash temperature to 100°F. Then, in the remaining four coolers, well water at 60°F is used to complete the cooldown to 80°F before the mash enters the fermentors.

#### Section 400 - Batch Fermentation

The fermentation section of the alcohol plant is shown on Drawing 345411-05. The fermentors receive mash continuously from the mash converter located in the mashing and saccharification section. The fermentors are batch operated and consists of sixteen 250,000 gallon vessels which are arranged in sets of four with one heat exchanger and circulation pump for each fermentor set. The fermentors are designed for a liquid loading of 80% of maximum capacity. Since cooling is needed for only about eight or ten hours out of the 48 hour fermentation cycle, one exchanger will service the needs of four fermentors. The fermentors are filled on a three hour cycle.

The yeast, *saccharomyces cervisiae*, is manually added to a yeast mix-tank and then transferred to the fermentor as it is filled (about 300 lb of yeast per batch). The yeast is purchased rather than manufactured on location. The inlet mash temperature is about 80°F, and the temperature gradually rises to a maximum of about 95°F during the peak fermentation period. Cooling is provided during this peak period by recirculation of the mash through the fermentor cooler. Well water at 60° is the cooling medium. Each fermentor requires a flow of approximately 1,200 gal/min during the peak period. The recirculation for cooling also serves to agitate the tank. At the end of the fermentation period, the fermentor contents are transferred to the Beer Well, TK-400, from which they are pumped continuously to the distillation section.

The fermentors are cleaned and sterilized by means of automatic spraying machines which are installed in each fermentor tank. Each tank has two such spraying machines. After each fermentation cycle, the tank is washed with a cleaning solution, sterilized with a iodine solution, and rinsed with clean sterile water in preparation for the next cycle.

#### Section 500 Distillation

The distillation section of the grain motor fuel alcohol plant is shown on drawing 345411-06.

Dilute beer feed from the fermentation section of the plant is collected in Tank, TK-400, the beer well, from which it passes continuously, via Pump P-416, to Heat Exchanger, E-525, in Section 500 of the plant.

The dilute beer feed, amounting to approximately 1150 gallons per minute, contains 7.1 weight percent alcohol and 6.92 percent solids. These occur in approximately equal amounts. The beer leaves the beer well at temperature of 90°F and undergoes a series of preheating steps before it enters the first stage of distillation. The dilute beer first passes in to the tube side of



Condenser-Preheater, E-525. In this unit, approximately 23% of the total preheating is accomplished. The first preheating step utilizes a portion of the vapors from the Dehydration Tower, T-523. These vapors are condensed to supply this first stage preheating. The warmed dilute beer feed next passes to Condenser-Preheater, E-516, where additional preheat, amounting to about 8.5% of the total, is added. In this condenser-preheater, a portion of the overhead vapors from the Pressure Stripper-Rectifier, T-514, is condensed to supply second stage preheat. The dilute beer feed next passes through two stages of feed preheating; wherein a portion of the heat in the bottom stream from the pressure stripper-rectifier tower is utilized in a two-stage flash operation. These stages add about 21.5% of the total feed preheating. The warm dilute beer feed next passes into Steam Condenser, E-506 where low pressure steam is used to accomplish additional preheating. Approximately 23% of the total feed preheat is added in Steam Condenser, E-506. The heating medium, in this case, consists of low pressure steam taken from other parts of the plant. The feed is finally preheated, approximately to saturation temperature, in an additional two-stage heating step, occurring in E-504 and E-505 which use flash heat taken from the bottom stream out of T-514, the Pressure Stripper-Rectifier.

Approximately 24% of the total feed preheating is accomplished in units E-504 and E-505.

The hot, saturated, dilute beer feed next passes into Degassing Drum, D-512, where carbon dioxide dissolved in the beer feed is flashed off. The carbon dioxide represents one of the by-products of the fermentation reaction. It is not recovered. Any alcohol or water vapor, accompanying the vented carbon dioxide, is condensed in Vent Condenser, E-515, from where it drains back to Flash Drum, D-512.

The saturated dilute beer feed enters the midsection of Tower T-514. Because of the high suspended solids content of the beer feed, the lower section of Pressure Stripper Rectifier, T-514, has been designed as a disc and donut type tower. This represents an effective contacting device which tends to be self-purging and does not allow the buildup of solids which would block ordinary distillation trays. Pressure Stripper-Rectifier, T-514, operates with a head pressure of 50 psig. The non-volatile soluble solids and suspended solids in the dilute beer feed wash down through the stripper section of the pressure-rectifier and a very dilute alcohol stream, containing less than 0.02 weight percent alcohol, is removed from the bottom of the tower. The dilute stillage containing the dissolved and suspended solids leaves the base of Tower, T-514, at about 304°. In the bottom section of T-514, the alcohol is effectively stripped from the dilute beer. The aqueous bottoms stream then passes through a series of flash stages. These stillage bottoms are subjected to progressive reduction in pressure through four flash stages. The flash vapor that develops in these stages is utilized to accomplish portion of the feed preheating as described previously. In these four flash stages, the temperature of the hot stillage is reduced from 304 degrees to approximately 212°F. The whole stillage, containing about 7.5% total solids, is next pumped by means of Pump, P-505, to Section 600 of the plant where the solids in the stillage are recovered as animal feed by-product.

Heat is supplied to the base of Pressure Stripper-Rectifier, T-514, by means of condensing 150 psig steam on the shell side of parallel forced circulation reboilers, E-511-A and E-511B.



Total steam supplied, to the base of T-514 through the shell sides of the reboilers, is 110, 000 pounds per hour.

The upper portion of the Pressure Stripper-Rectifier, T-514, contains perforated trays and has a reduced diameter compared to the stripping section. The lower section of T-514 is 138 inches in diameter while the top section of the tower, containing 28 perforated trays, has a diameter of 102 inches.

Alcohol-rich vapors, generated in the Pressure Stripper-Rectifier, T-514, pass overhead from the tower at a temperature of about 250°F and a pressure of 50 psig. These vapors may be utilized as a source of heat by condensing in the reboilers which are attached to the base of the Dehydration Tower, T-523, and the Hydrocarbon Stripper, T-532. The overhead vapor from the Pressure Stripper-Rectifier contains 95 volume percent alcohol (190 proof). Vapor condensate from E-516, from the reboilers on the Dehydration Tower, T-523, and the Reboiler of the Hydrocarbon Stripper, T-523, are all collected and pumped back to Reflux Drum, D-519. The total condensate is returned via P-518 to the top tray of the Pressure Stripper-Rectifier, T-514.

The upper five trays of the Pressure Stripper-Rectifier operate in a total reflux condition. The liquid product from the Pressure Stripper-Rectifier is removed as a liquid side draw stream about five trays from the top of the tower. From here it passes to the midsection of Dehydration Tower, T-523.

Dehydration Tower, T-523, is 138 inches in diameter and contains 50 perforated trays. The tower operates at essentially atmospheric pressure. The bottoms stream from T-523 represents the anhydrous motor fuel grade alcohol and has a concentration of 99.5 volume percent ethanol (199 proof), the balance being water. The bottoms stream from the dehydration is pumped by P-524 through Product cooler, E-520, which utilizes cooling water to reduce the temperature of the product alcohol to about 100°F. The cooled product next passes to product storage in Section 700.

Heat is supplied to the base of the Dehydration Tower, T-523, through parallel forced Circulation Reboilers, E-521A and E-521B. The overhead product from the dehydration tower is a ternary minimum boiling azeotrope consisting of hydrocarbon, alcohol, and water. A portion of these vapors is condensed in Primary Condenser, E-526, which utilizes cooling water to remove the heat of condensation of these vapors. The condensed vapors from E-525 and E-526 pass to Reflux Cooler, E-529, where they are further subcooled by cooling water. The subcooled liquid then passes to Decanter, D-528.

The subcooled liquid entering Decanter, D-528, separates into two layers. The upper layer is largest in volume and represents the hydrocarbon-rich layer. The lower layer, is a water-rich layer containing some alcohol and hydrocarbon. The upper layer of from the decanter is pumped by means of P-531, back to the top tray of the Dehydration Tower, T-523.

The lower layer from the decanter is pumped by P-530 to the top tray of Hydrocarbon Stripper, T-532. Hydrocarbon Stripper, T-532, serves to strip the remnants of hydrocarbon and



alcohol contained in the feed to the top tray. The bottom stream from T-523 is an essentially aqueous stream which is removed via P-534 and is sent to the waste treatment plant in Section 800. Thermal energy is supplied to the base of Hydrocarbon Stripper, T-532, via alcohol-rich vapor condensing on the shell side of Reboiler, E-536. The condensed alcohol-rich vapor is passed by means of P-535 back to reflux drum, D-519, where it joins other vapor condensate before being returned to the top tray of the Pressure Stripper-Rectifier, T-514. Overhead vapors from Atmospheric Pressure Hydrocarbon Stripper, T-532, containing alcohol, hydrocarbon, and water, pass to Condenser-Preheater, E-525, where they are condensed. The condensate is returned through Reflux Cooler, E-529 to Decanter, D-528. The aqueous stream passing from the bottom of the Hydrocarbon Stripper contains less than 0.02 weight percent alcohol.

In the yeast fermentation process, certain extraneous products, in addition to ethyl alcohol, are formed. These are, generally, higher alcohol, i.e. higher molecular weight alcohols which are known as fusel oils, and light ends which include such things as aldehydes, etc. The fusel oil and light ends must be removed because their presence would upset the equilibrium associated with the dehydration step, and could bring about problems in the decantation step occurring in Decanter, D-0538.

The distillation system shown in Drawing 345411-06 provides for the removal of these extraneous components in the following way: The higher alcohols, or fusel oils, have the property of being more volatile than alcohol in dilute aqueous solution, but they are less volatile than alcohol in concentrated alcohol solution. For this reason, they tend to concentrate on some tray in the rectifying section of the Pressure Stripper-Rectifier, T-514. These fusel oils, thus having concentrated, can be removed as a liquid side draw stream from the pressure stripper-rectifier. They are removed and passed through Fusel Oil Cooler, E-537. From there, they pass to Fusel Oil washer, T-538. Fusel Oil Washer, T-538, is nothing more than a water extraction column in which the alcohol content of the fusel oils is washed from them, under reduced temperature, by counter-currently contacting the cooled fusel oil side stream with a stream of cold water. The heavy aqueous stream, containing the extracted ethyl alcohol is removed from the base of Fusel Oil Washer, T-538, via P-539. This stream is returned to the lower section of Pressure Stripper-Rectifier, T-514, for alcohol recovery. The light fusel oil stream is decanted from the top of Fusel Oil Washer, T-538, and passes to TK-540, the Fusel Oil Storage Tank.

In general, the fermentation process, when utilizing corn, will produce about 4 to 5 gallons of fusel oil for every 1000 gallons of anhydrous alcohol product. These fusel oils do have a heating value and can be reblended into the product. If this reblending operation is not desired then the fusel oils may be passed to the plant boiler where they are used as fuel.

Light extraneous products from fermentation, such as aldehydes, are effectively removed in this distillation system by withdrawing a very small purge from the total reflux stream passing back to the top tray of pressure stripper-rectifier, T-514. This light component purge, in general, cannot be reblended into the alcohol which is to be used for motor fuel blending. Therefore, these materials are removed and sent to the plant boiler where their fuel value is recovered. The light ends purge stream passes to Section 800.



The distillation scheme for producing motor fuel grade alcohol, as depicted in Drawing 345411-06 utilizes only 17.5 pounds of process steam per gallon of anhydrous motor fuel grade alcohol product. This great reduction in energy use is accomplished by optimizing the feed preheating scheme and by utilizing the heat content of high pressure vapors produced in the pressure Stripper-Rectifier, T-514, to supply the reboil heat for both the dehydration step, carried out in T-523, and the hydrocarbon-alcohol stripping occurring in T-532.

#### Section 600 - Evaporation and Drying of Stillage Residue

Flowsheets for this area are shown on Drawings 345411-07 and 345411-08. Stillage from the distillation area is delivered to the Whole Stillage Tank, TK-600, from which it is pumped to the solid bowl centrifugals which operate on a continuous basis. These centrifugals separate the whole stillage into two fraction: thin stillage containing 6.5-10% total solids and thick stillage containing about 35% total solids. Part of the thin stillage (corresponding to 10% of the total mash) is recycled to the mash mixing tank in the cooking and saccharification section.

The remaining thin stillage is evaporated in a vapor recompression evaporator to about 55% solids. Because of a cooling effect in the centrifugal separators (caused by evaporation of the stillage in contact with air), the thin stillage must be reheated from about 165°F to 208°F before it enters the evaporator. Heating is accomplished by using evaporator condensate which is cooled from 230°F to 185°F. Power for driving the evaporator vapor compressor (approximately 6,200 hp) is provided by a steam turbine which uses 580 psig steam and exhausts at about 160 psig. This exhaust steam is used for distillation, for mash cooking, and for heating supplemental air for spent grains drying. The vapor compressor operates at approximately atmospheric pressure at the inlet and compresses the vapor to about 21 psia. The compressor outlet stream is superheated, but before it enters the evaporators it is desuperheated by injection of condensate. The water vapor from the evaporator bodies passes through entrainment separators and then to the vapor compressor. However, before entering the compressor, it is superheated by mixing with a recycle flow of superheated vapor from the compressor outlet.

The thick stillage is mixed with the concentrated thin stillage and with recycled dry grains in the Wet Grains Minglers, ML-636A, ML-636B, and ML-636C. The amount of dry grains recycle is regulated to maintain a wet grains moisture content of 30% in order to minimize stickiness.

The wet grains are then fed to the Rotary Dryers, DR-639A/B/C. The grains are tumbled in the dryers in contact with hot flue gas which comes from the power boiler. Supplemental hot air for drying is provided by the Air Heater, E-628, which uses 150 psig steam for heating. The hot gas enters the dryers at about 600°F with a wet bulb temperature of about 145°F. The flue gas goes through Cyclone Collectors, CC-630A, CC-630C, to remove most of entrained solids before it is delivered to the flue gas scrubber.

The dry grains, at about 10% moisture, are transferred to the Dry Grains hopper, H-645. About 75% of the dry grains is recycled in order to regulate the moisture content of the wet grains. The remaining net make of dry grains is ground in a hammer mill and then cooled in the



product Cooler, E 634, which is an auger-type heat exchanger that uses well water to cool the grains to about 100°F. The cooled by-product is transferred pneumatically to Storage and Shipping, Section 700.

### Section 700 - Alcohol and Dry Grains Storage and Shipping

Alcohol storage and shipping are shown in Drawing 345411-09 and dry grains by-products storage and shipping are shown in Drawing 345411-10.

The alcohol is received from the distillation section and stored in Receiver Tanks, TK-701 and TK-702. Each of these tanks is sized for one day of production. While one tank is being filled, the other one will be checked for quality and quantity. After inspection, its contents will be sent to long-term storage. The four storage tanks, TK-706, TK-707, TK-708, and TK-709, hold a total of about 4,200,000 gallons which is about 28 days of production. Upon transferring the product from storage to a tank car or tank truck, denaturant (gasoline) is added at a rate of 1 gallon per 100 gallons of alcohol. The denaturant tank, TK-704, holds about 50,000 gallons. Accurate metering is provided by MT-711 and MT-712 which are positive displacement meters.

Dry grains are stored in an A-frame type building having a storage capacity of about 295,000 cu ft, equivalent to about one weeks production. Shipping of the dry grains from storage is done a first in, first out basis and utilizes a front-end loader to load the pneumatic conveyor system which transfers the grains to the Live Bottom Surge Bin, SB-722, at a rate of 88,000 lbs per hour. This rate is based on shipping out the dry grains for an average of 12 hours out of each day. Shipment may be made by either truck or rail, and Shipping Scales, SC-724 and SC-725, are provided for weighing the shipments.

### Section 800 - Utilities

Utilities and General Services are shown on Drawings 345411-11 through 345411-13; for convenience, all the boiler related equipment is in Section 800-A and all the non-boiler related equipment is in Section 800-B.

Steam for the plant is provided by a coal fired boiler. The flowsheet for this section is shown on Drawing 345411-11. The boiler is rated at 250,000 lb/hr of steam at 600 psig and 600°F. Calculated plant usage is about 200,000 lb/hr of steam. The firing rate is 12.6 T/hr coal, having a heating value of 10,630 Btu/lb. Minor fuel inputs are also provided by light ends from distillation of the alcohol and by dewatered sludge from waste treatment. The high pressure steam is sent through an extraction turbine that exhausts steam at 150 psi. The turbine provides 6200 HP for the vapor compressor on the stillage evaporator in Section 600. The exhaust steam is used for distillation, drying and cooking duties in the plant.

The coal unloading facility provides for direct transfer to the Coal Bunker BU-808, or to a storage pile. A front end loader is used to transfer coal from the pile back to the unloading area where it can then be transferred to the coal bunker.



Boiler feedwater is provided by condensate return from the process, where possible, and by makeup water that has been filtered and conditioned in a conventional boiler feedwater treatment system. About two-thirds of the boiler feedwater is condensate return.

The flue gas passes through the Cyclone Collector, CC-806, for particulate removal. The collector consists of numerous small cyclones (multi-clones) housed in a single chamber. The recovered particulate goes to the boiler ash pit. The flue gas exits the boiler at a temperature of about 725°F. This is a high flue gas temperature by normal standards, but in this case it does not affect overall plant thermal efficiency since the hot flue gas, tempered with air to 600°F, goes to the stillage drying section where its heat is used to dry the distiller's grains. For this reason, no flue gas heat economizer or flue gas stack is required with the boiler.

The coal is fed to the boiler by four stoker-spreader units. The spreader feeding system was selected (rather than pulverized blown coal) because of the small boiler size and because the boiler inefficiency, due to excess air, does not effect the process thermal efficiency.

The water supply system for the plant is shown on Drawing AN493-12. The system provides well water for meeting process makeup requirements, for process cooling where cooling tower water is not cool enough, and for maintaining a supply of fire protection water. Three wells are provided with a capacity of 1800 gpm each. The Well Water Storage Tank, TK-832, has a capacity of 100,000 gallons and provides for surges in demand and allows short-term shutdowns of the wells, as required for maintenance or repairs, without interrupting the supply of water to the plant.

The fire protection system consists of the Fire Protection Tank, TK-834, which has a capacity of 300,000 gallons, four fire water pumps (2 electric and 2 diesel), and an underground fire water distribution system, along with the appropriate fire hydrants and spray headers. Each pump has a capacity of 2000 gpm. The diesel powered pumps are used only in the event of an electric power failure.

The Cooling Tower, CT-890, is designed to provide 16,000 gpm of water at 85°F from a warm water return temperature of 115°F, and an ambient design wet bulb temperature of 75°F. The tower consists of two cells with a two speed fan for each cell. The three Cooling Tower Pumps, P-891A/B/C are rated at 7500 gpm each.

The waste water flows include process waste water and sanitary waste water. The waste water is collected at a lift station and pumped to the treatment plant.

The waste water treatment plant is designed for secondary treatment with two extended aeration tanks and two settling tanks. The aeration tanks are 95 ft in diameter. The sludge thickening tank is 20 ft in diameter.

The influent stream passes through a bar screen and grinder prior to entering the first aeration tank. Water from the first stage is split, the major portion is recycled to the first aeration stage, while the remainder is sent to the thickening tank. Clarified water from the first



settling stage overflows to the second aeration tank, where additional BOD is removed. Nutrients may be added to either aeration tank, but due to the nature of the waste water flows, nutrients should not be needed. The water from the second aeration tank overflows to the second stage settling tank.

The sludge from the second stage settling tank is recycled to either the first or second stage aeration tank. A makeup stream is sent to the thickener. The two stage aeration system, coupled with the flexibility to recycle sludge from either stage, allows good control of effluent BOD.

The clarified water from the second stage settling tank flows by gravity to the chlorine contact tank. Chlorine is added to the contact tank for destruction of final traces of impurities. The effluent from the chlorine tank flows to a nearby river.

Sludge from both the first and second stage aeration tanks is collected in the sludge thickener and is pumped from the thickener to the dewatering press. The sludge is dewatered to about 25% solids. The solids from the dewatering press are chopped up in a flaker and conveyed to the boiler for burning.

The electric power is purchased and provision is made in Section 800 B for the electrical distribution and control network in the plant. The power required is 6540 KW in the plant.

### Capital Cost

The equipment lists for each section of the base case design are given in Tables 2 through 8. The column labelled Estimated Cost (1978) is directly from the Katzen reports for the delivered or purchased cost of the major equipment items. The Chemical Engineering Plant Cost Index (CEI) for 1978 is 219. The columns labelled Estimated Cost 1992 gives the updated cost by applying a CEI value of 362. Furthermore, when the material of construction is changed from carbon steel in the original Katzen design to 304 SS, the updated cost is multiplied by a factor of 2.2. The total delivered cost of each section is given at the end of the corresponding equipment tables.

The total fixed capital of the of the plant is assembled in Table 9. For each section the corresponding delivered equipment cost is taken from the equipment table. The Chilton factors are applied to show how the fixed capital of each section is developed. The values selected are based on the complexity of the section and past experience. At the end of Table 9, the fixed capital for the entire plant is given. For convenience the utility section is broken into two sections, 800-A for the boiler related equipment and 800-B for the non-boiler related equipment so comparison with the Biostil process will be obvious.

### Operating Cost

The operating cost is developed in Table 10. The material usage is shown on an annual basis for each item. These are taken directly from the Katzen report. The labor is broken down



into plant operators (including supervisors), labors, technicians, and maintenance workers. This staffing allows 24 hours per day operation. This manning sums to 130 people, which is consistent with the levels seen on our plant visits. Note that there are a high number of people in maintenance. The major job is keeping heat exchangers of all types clean. In the distillation section the reboilers of the beer still are a particular problem, in part because of the high temperature at which they operate when the column is at 50 psig. In one plant we saw that one reboiler in a set of three on the beer still was cleaned a day.

The energy cost for coal and electricity are based on usage given by Katzen's report. The cost of coal at \$25 per ton and electricity at 5¢ per KWH is typical of 1992 Illinois location.

The capital related costs are made of investment depreciation at 11.11% per year for a 9 year write-off, insurance at 1.0% and maintenance materials at 2.5% of total capital. For convenience the total capital investment is given on the operating cost sheet.

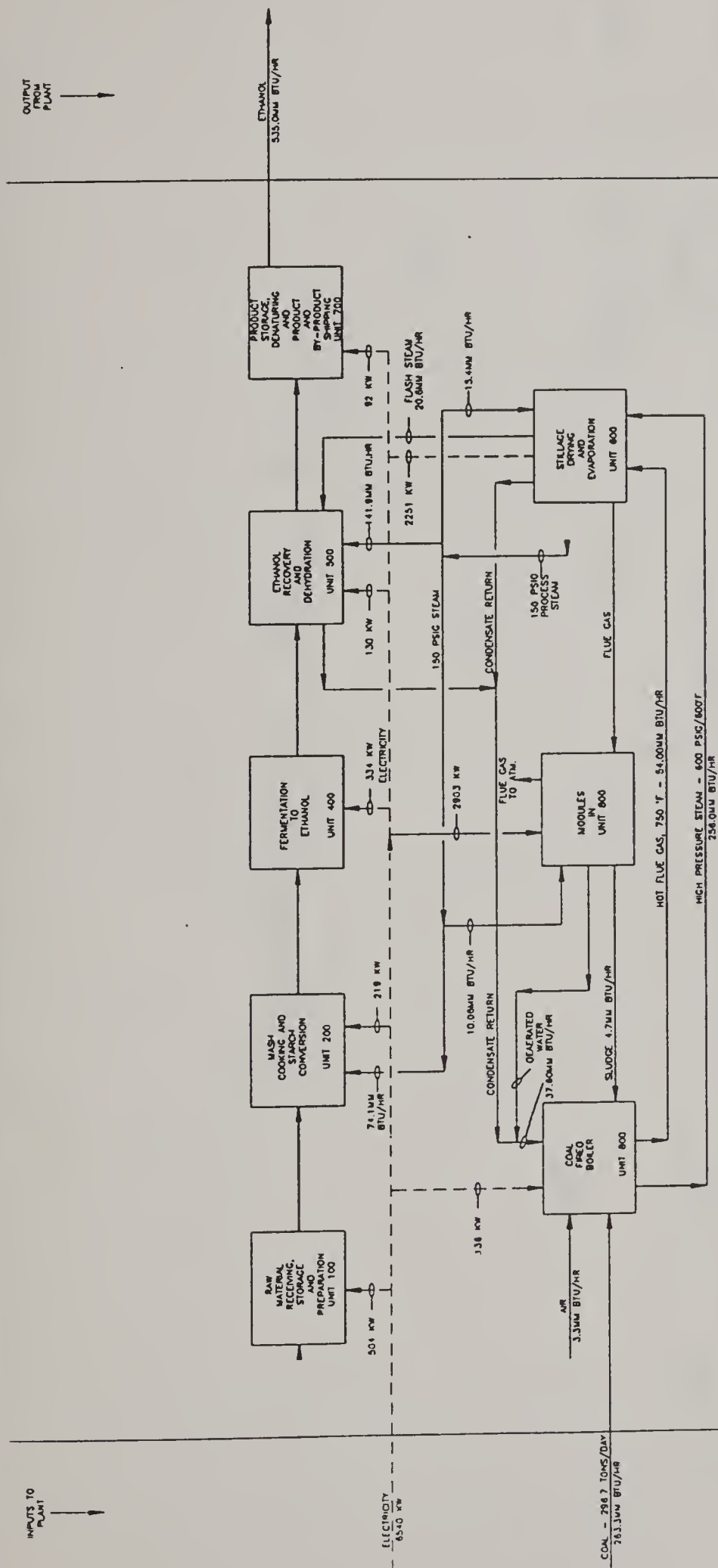
The total annual cost of production is given in line E in Table 10. Then allowance is made for the credit from the sale of DDGS at \$120 per ton - typical of today's price. The net operating cost is given on line G.

In order to see the effect of changes in key costs, a sensitivity analysis is given in Table 11.







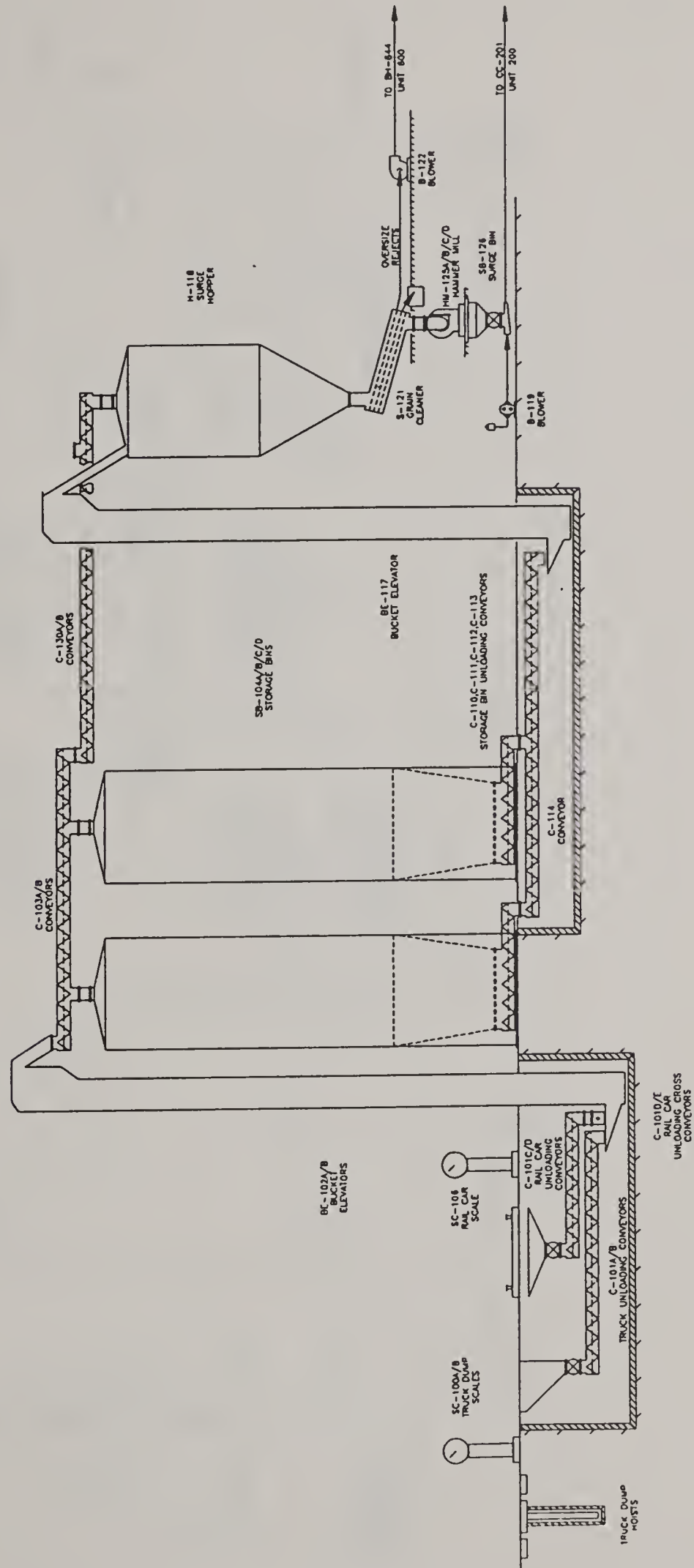


ENERGY USE FOR BASE CASE

DATE	DATE 7/1/82	REVISION	
CHG BY	DATE		
PROJECT NO.	34-5411		
SY. NO.	345411-02		







SECTION 100 - GRAIN STORAGE AND HANDLING FOR BASE CASE

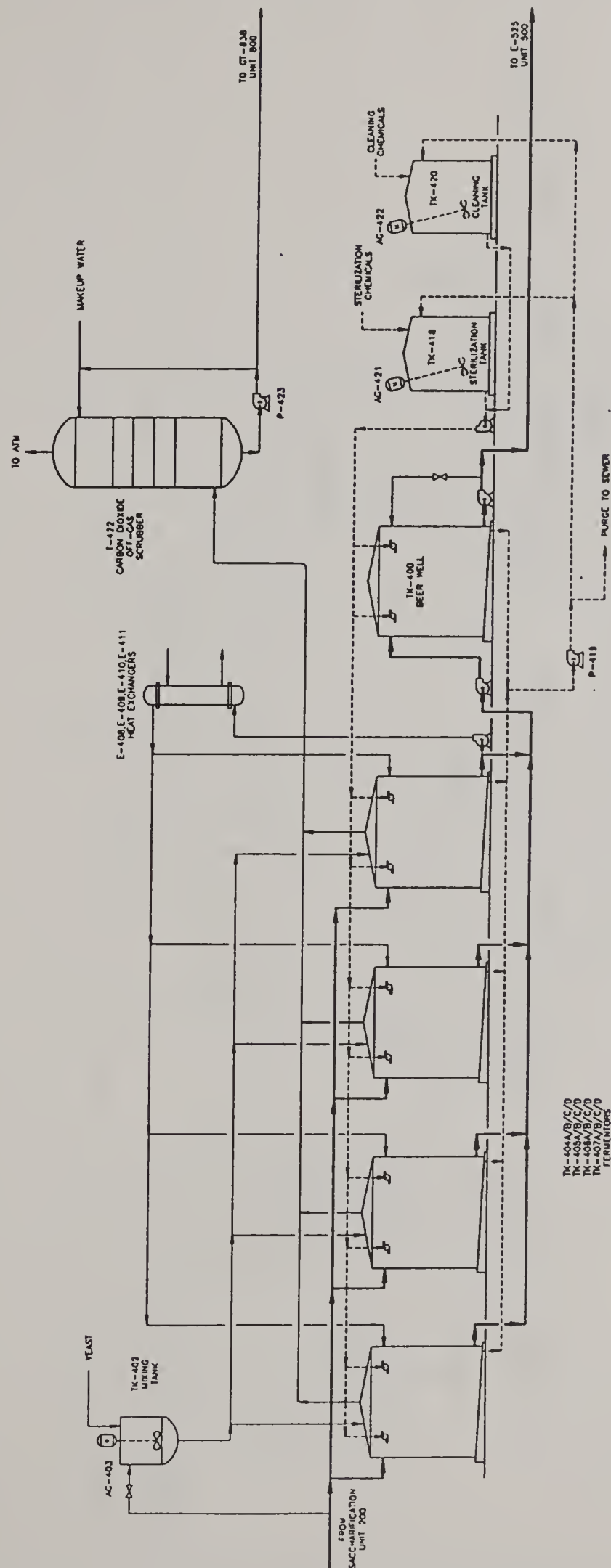
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DATE	7/1/82
BY	DATE
PROJECT NO.	34-3411
SC. NO.	345411-03











TK-401A/B/C/D  
TK-403A/B/C/D  
TK-404A/B/C/D  
TK-405A/B/C/D  
FERMENTATIONS

SECTION 400 - FERMENTATION FOR BASE CASE



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PROJECT NO.	34-5411	DATE	34-5411-03
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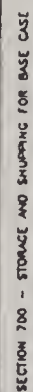










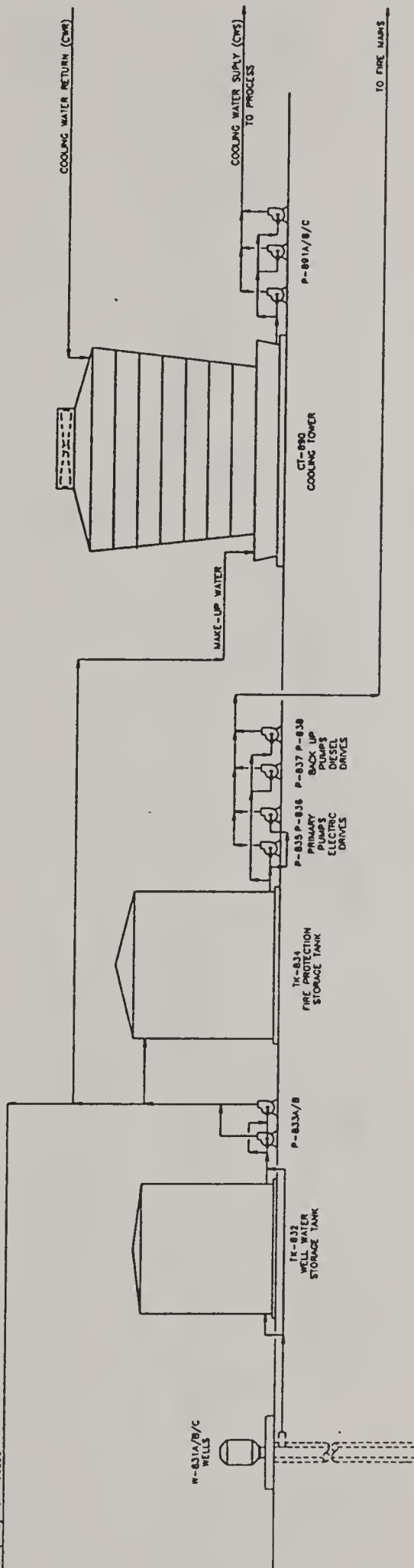








WELL WATER SUPPLY (WWS) TO PROCESS



SECTION 800-B - NON-BOLLER RELATED UTILITIES FOR BASE CASE

		DATE 7/1/92	REVISED
		DATE	
DATE 7/1/92	DATE		
PROJECT NO. 34-5411	PROJECT NO.		
SOL. NO. 345411-12	SOL. NO.		







TABLE 2. Equipment List for Base Case Technology  
Section 100 - Grain Storage and Handling

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
SC-100A/B	truck dumper, pit type with scale, Kewanee DS-50-2 dumper, scale, electronic system, 50 T cap (2 required)	amb.	std.	\$90,000	\$148,767
C-101A/B	screw conveyor (trucks), length = 70 ft, cap = 4,000 bu/hr, 10 hp (each) (2 required)	amb.	std.	\$18,000	\$29,753
C-101C	screw conveyor (r.r. car), length = 90 ft, cap = 4,000 bu/hr, 16 hp	amb.	std.	\$9,500	\$15,703
C-101D/E	screw conveyor (cross-link), length = 35 ft, cap = 4,000 bu/hr, 5 hp (each) (2 required)	amb.	std.	\$8,000	\$13,224
BE-102A/B	bucket elevator lifts, 92 ft high, cap = 4,000 bu/hr, 15 hp (each) (2 required)	amb.	std.	\$24,000	\$39,671
C-103A/B	distributing conveyors, screw type, length = 120 ft, cap = 4,000 bu/hr, 15 hp (each) (2 required)	amb.	std.	\$25,000	\$41,324
SB-104A/B/C/D	grain storage bins, 60 ft dia x 58 ft 10 in, straight side with 15° cone top, nom cap = 150,000 bu (each) (4 required)	amb.	C.S.	\$560,000	\$925,662
SC-106	rail car scale, 150 T capacity, Fairbanks model 12-1304	amb.	std.	\$75,000	\$123,973
C-110 thru C-113	storage bin bottom, screw conveyors, length = 35 ft, cap = 2,500 bu/hr, 5 hp (each) (4 required)	amb.	std.	\$15,000	\$24,795
C-114	screw conveyor, length = 120 ft, cap = 2,500 bu/hr, 10 hp	amb.	std.	\$10,000	\$16,530
BE-117	bucket elevator lift, 90 ft 4 in high, cap = 2,500 bu/hr, 10 hp	amb.	std.	\$10,000	\$16,530
H-118	hopper surge bin, 20 ft dia x 23 ft, straight side, 60° cone bottom, 30° cone top, nom cap = 7,500 bu	amb.	C.S.	\$18,000	\$29,753
B-119	pneumatic transport blower, rotary positive displacement, 3,900 cfm, 200 hp	amb.	by mfr.	\$51,500	\$85,128
S-121	grain cleaner, eureka, size 12, cap = 2,500 bu/hr 10 hp	amb.	C.S.	\$12,000	\$19,836
B-122	blower (included with item S-121)	amb.			\$0
HM-125A/B/C/D	hammer mill, sprout waldron mode 4812 with guards, 150 hp	amb.	by mfr.	\$48,900	\$80,830
SB-126	surge bin (included with item NH-125)				\$0
C-130A/B	storage bypass screw conveyors, length = 53 ft, cap = 4,000 bu/hr, 7.5 hp (each) (2 required)	amb.	std.	\$10,000	\$16,530
	Total Equipment, Section 100			\$984,900	\$1,628,008



TABLE 3. Equipment List for Base Case Technology  
Section 200 - Cooking and Saccharification

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
CC-201	meal cyclone collector	3900 acfm	std.	\$2,500	\$4,132
TK-202	meal surge tank (including scale), 7 ft dia x 7 ft side, cone bottom, 7,000 lb cap	amb.	C.S.	\$8,000	\$13,224
FV-203A/B	rotary feeder valve, 24 in x 22 in rotor, 31 rpm, 2 hp (2 required)	8,500 ft <sup>3</sup> /hr	std.	\$11,200	\$18,513
TK-204	batch weight tank, 9 ft x 9 ft side, cone bottom, 14,000 lb cap	amb.	C.S.	\$5,300	\$8,761
SV-205	slide valve, air operated, 24 in size		std.	\$1,000	\$1,653
TK-206	continuous weigh tank, 18 ft dia x 18 ft straight side, cone bottom (including scale)	amb.	C.S.	\$46,100	\$76,202
FV-207	rotary feeder valve, 24 in x 22 rotor, 31 rpm, 2 hp	4,250 ft <sup>3</sup> /hr	std.	\$5,600	\$9,257
AG-208	mixing tank agitator, 84 rpm, 15 hp		C.S.	\$4,500	\$7,438
TK-209	mash mixing tank, 7 ft 6 in dia x 7 ft 6 in, straight side, cone bottom, 2,500 gal cap	atm. 200°F	304SS	\$3,200	\$11,637
P-210	mash mixer pump, centrifugal, 1000 gpm, 50 ft TDH, 30 hp		d.i.	\$2,200	\$3,637
TK-211	mash pre-cooker, 10 ft dia x 10 ft straight side, cone bottom, 6,500 gal cap	atm. 200°F	304SS	\$7,000	\$25,456
AG-212	pre-cooker agitator, 84 rpm, 25 hp		304SS	\$5,500	\$20,001
P-213	pre-cooker pump, 1,000 gpm, 400 ft TDH, 200 hp		d.i.	\$14,000	\$23,142
PLR-214A/B	mash cookers, 9-20 ft long x 10 in, sch 40 pipes, 2/8-180° return bends (2 required)		304SS	\$16,200	\$58,912
TK-215A/B	pressure flash tank, 6 ft dia x 8 ft straight side, dished heads (2 required)	25 psig 300°F	304SS	\$10,400	\$37,820
TK-216A/B	vacuum flash tank, 7 ft 6 in dia x 10 ft, straight side, dished heads (2 required)	full vacuum, 200°F	304SS	\$19,800	\$72,003
SR-217A/B	pressure flash entrainment separator, 30,000 lb/hr steam @ 15 psig	25 psig, 300°F	C.S.	\$11,200	\$18,513
SR-218A/B	vacuum flash entrainment separator, 15,000 lb/hr steam @ 3.3 psia	full vacuum, 200°F	C.S.	\$13,200	\$21,819
P-219	fungal amylase mash pump, 150 gpm, 30 ft TDH, 5 hp		d.i.	\$1,100	\$1,818
MX-220A/B	fungal amylase mixer, 48 in dia x 90 in long, w/15 hp agitator (2 required)	full vacuum	304SS	\$16,600	\$60,366



TABLE 3. Equipment List for Base Case Technology  
Section 200 - Cooking and Saccharification

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
PLR-222	pipeline saccharifier, 12-30 ft long x 12 in, sch 40 pipes, w/11-180° return bends		304SS	\$21,300	\$77,458
E-223 A thru J	mash coolers, $ZQ=35.7\text{MM btu/hr}$ , $A=1,141\text{ ft}^2$ (each) (10 required)	100 psig, 220°F	C.S. shell, 304 SS tubes	\$365,000	\$603,333
E-224	flash vapor condenser, $Q=28.2\text{MM btu/hr}$ , $A=4,170\text{ ft}^2$	full vacuum, tube side, 150 psig, 220°F, shell side	304 SS tubes, C.S. shell	\$75,000	\$123,973
EJ-225	steam ejector, 90 lb/hr motive steam @ 150 psig	30 lb/hr, air-3.3 psia		\$800	\$1,322
E-226	ejector condenser, $Q=0.1\text{MM btu/hr}$ , $A=10\text{ ft}^2$	150 psig, 400°F	C.S. shell, 304 SS tubes	\$800	\$1,322
TK-227	hot well, 5 ft dia x 5 ft high, flat bottom, loose cover	1 atm., 220°F	C.S.	\$1,400	\$2,314
P-228	hot well pump, 200 gpm, 30 ft TDH, 5 hp		d.i.	\$1,100	\$1,818
E-229	mash heater, $Q=33.8\text{MM btu/hr}$ , $A=4,400\text{ ft}^2$	25 psig, 300°F	C.S. shell, 304 SS tubes	\$80,000	\$132,237
TK-230	condensate flash tank, 2 ft dia x 3 ft, straight side	1 atm., 220°F	C.S.	\$300	\$496
	Total Equipment, Section 200			\$750,300	\$1,438,578



TABLE 4. Equipment List for Base Case Technology  
Section 400 - Fermentation

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
TK-400	beer well, 35 ft dia x 35 ft high, cone top, sloped bottom, nom cap = 250,000 gal	atm., 120°F	304SS	\$65,000	\$236,374
P-401	beer well pump, centrifugal, 1,340 gpm, 50 ft TDH, 25 hp	25 psig, 150°F	316 SS	\$3,800	\$6,281
TK-402	yeast mix tank, 7 ft dia x 5 ft high, w/agitator, flat top, dished bottom, nom cap = 1,500 gal	atm., 150°F	304 SS	\$13,500	\$22,315
AG-403	yeast mixing agitator, 1,150 rpm, 1.5 hp	atm., 150°F	304 SS	\$1,500	\$2,479
TK-404 A/B/C/D through TK-407 A/B/C/D	fermentors, 35 ft dia x 35 ft high, cone roof, sloped bottom, nom cap = 250,000 gal (16 required)	atm., 120°F	304SS	\$1,128,000	\$4,102,005
E-408 through E-411	heat exchangers, A = 4,300 ft <sup>2</sup> (each) (4 required)	tubes - 100 psig, 150°F; shell - 100 psig, 150°F	304 SS; C.S., tube sheet: 304 SS (clad)	\$416,000	\$687,635
P-412 through P-415	recycle pumps, 2,000 gpm, 80 ft TDH, 60 hp (each) (4 required)	100 psig, 150°F	316 SS	\$22,000	\$36,365
P-416	distillation feed pump, centrifugal, 1,500 gpm, 400 ft TDH, 200 hp	170 psig, 150°C	316 SS	\$25,000	\$41,324
P-417	sterilization pump, 200 gpm, 200 ft TDH, 15 hp	amb.	304SS	\$2,300	\$8,364
TK-418	sterilization tank, 12 ft dia x 12 ft high, nom cap = 10,000 gal, w/2 hp agitator	atm., amb.	304SS	\$9,200	\$33,456
P-419	cleaning pump, 300 gpm, 50 ft TDH, 5 hp	30 psig, 150°F	304SS	\$2,300	\$8,364
TK-420	cleaning tank, 12 ft dia x 12 ft high, nom cap = 10,000 gal, 2/2 hp agitator	atm., amb.	304SS	\$9,200	\$33,456
CL-421	cleaning machines (34 required)	175 psig, 150°F	316 SS	\$54,000	\$89,260
T-422	CO <sub>2</sub> offgas scrubber, 60 in dia, 5 perf trays	atm., 100°F	304SS	\$10,000	\$36,365
P-423	scrubber recycle pump, 150 gpm, 50 ft TDH, 1 hp	100°F	D.I.	\$1,000	\$1,653
	Total Equipment, Section 400			\$1,762,800	\$5,345,699



TABLE 5. Equipment List for Base Case Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
P-501	whole stillage pump, centrifugal, 1,200 gpm, 100 ft TDH, 50 hp	40 psig, 250°F	316 SS	\$4,400	\$7,273
E-502	4th stage flash condenser/preheater, Q = 10.7 MM btu/hr, A = 2,324 ft <sup>2</sup>	tubes - 150 psig, 300°F; shell - 50 psig, 300°F (floating head 6 pass)	304 SS; C.S. w/corrosion allowance	\$60,000	\$99,178
E-503	3rd stage flash condenser/preheater, Q = 11.5 MM btu/hr, A = 2,356 ft <sup>2</sup>	tubes - 150 psig, 300°F; shell - 50 psig, 300°F (floating head 6 pass)	304 SS; C.S. w/corrosion allowance	\$64,000	\$105,790
E-504	2nd stage flash condenser/preheater, Q = 12 MM btu/hr, A = 2,324 ft <sup>2</sup>	tubes - 150 psig, 325°F; shell - 75 psig, 350°F (floating head 6 pass)	304 SS; C.S. w/corrosion allowance	\$63,000	\$104,137
E-505	1st stage condenser/preheater, Q = 13.3 MM btu/hr, A = 2,454 ft <sup>2</sup>	tubes - 150 psig, 325°F; shell - 75 psig, 350°F (floating head 6 pass)	304 SS; C.S. w/corrosion allowance	\$66,000	\$109,096
E-506	steam preheater, Q = 23.6 MM btu/hr, A = 1,106 ft <sup>2</sup>	tubes - 150 psig, 300°F; shell - 25 psig, 300°F (floating head 6 pass)	304 SS; C.S.	\$34,000	\$56,201
D-507	4th stage flash drum, 5 ft dia x 8 ft high, dished heads	50 psig, 300°F	304 SS	\$5,000	\$18,183
D-508	3rd stage flash drum, 5 ft dia x 8 ft high, dished heads	50 psig, 300°F	304 SS	\$5,000	\$18,183
D-509	2nd stage flash drum, 5 ft dia x 8 ft high, dished heads	75 psig, 325°F	304 SS	\$5,500	\$20,001



TABLE 5. Equipment List for Base Case Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
D-510	1st stage flash drum, 5 ft dia x 8 ft high, dished heads	75 psig, 325°F	304 SS	\$5,500	\$20,001
E-511 A/B	stripper/rectifier reboiler, total Q = 94.4 MM btu/hr, two units required with A = 3,350 ft² each	tubes - 75 psig, 350°F / shell - 175 psig, 400°F	304 SS/C.S.	\$140,000	\$231,416
D-512	degasser drum, 5 ft dia x 6 ft high, ASME F&D heads, top and bottom	100 psig, 350°F	304 SS	\$5,300	\$19,274
P-513	dehydration column reboiler pump, centrifugal, 3,500 gpm, 30 ft TDH, 50 hp	75 psig, 350°F	D.I.	\$3,500	\$5,785
T-514	stripper/rectifier - 2 sections: bottom section - stripping-138 in dia, 87 disc and donut trans; top section - rectification-102 in dia, 28 perforated trays	75 psig, 325°F	304 SS	\$238,000	\$865,494
E-515	degassing vent condenser, Q = 500,000 btu/hr, A = 100 ft²	tubes - 75 psig, 300°F / shell - 75 psig, 300°F	304 SS / C.S.	\$5,000	\$8,265
E-516	vapor condenser/preheater, Q = 8.8 MM btu/hr, A = 538 ft²	tubes - 150 psig, 250°F / shell - 75 psig, 250°F (floating head single pass)	304 SS / C.S. w/corrosion allowance	\$32,000	\$52,895
E-517	rectifier vent condenser, Q = 7.5 MM btu/hr, A = 1,500 ft²	tubes - 75 psig, 250°F / shell - 75 psig, 250°F	304 SS / C.S. w/corrosion allowance	\$39,000	\$64,466
P-518	rectifier reflux pump, centrifugal, 650 gpm, 170 ft TDH, 40 hp	110 psig, 275°F	304 SS	\$3,400	\$5,620



TABLE 5. Equipment List for Base Case Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
D-519	rectifier reflux drum, 6 ft dia x 5 ft high, dished heads	75 psig, 275°F	304 SS	\$4,200	\$15,273
E-520	product cooler, $Q = 3.1$ MM btu/hr, $A = 350$ ft <sup>2</sup>	tubes - 50 psig, 200°F / shell - 75 psig, 150°F	304 SS / C.S. w/ corrosion allowance	\$20,000	\$33,059
E-521	condenser/reboiler, total $Q = 65.6$ MM btu/hr, two units required with $A = 3490$ ft <sup>2</sup> each	tubes - 75 psig, 275°F / shell - 30 psig, 275°F	304 SS / C.S. w/ corrosion allowance	\$180,000	\$297,534
P-522	dehydration-reboiler pump, 2,500 gpm, 30 ft TDH, 20 hp	30 psig, 250°F	D.I.	\$4,600	\$7,604
T-523	dehydration tower, 138 in dia, 50 perforated trays	15 psig, 250°F	304 SS	\$164,000	\$596,391
P-524	product pump, 150 gpm, 72 ft TDH, 3 hp	50 psig, 250°F	D.I.	\$1,100	\$1,818
E-525	dehydration condenser preheater, $Q = 23.6$ MM btu/hr, $A = 4,456$ ft <sup>2</sup>	tubes - 150 psig, 200°F / shell - 15 psig, 200°F (floating head 6 pass)	304 SS / C.S. w/corrosion allowance	\$94,000	\$155,379
E-526	dehydration condenser, $Q = 40.8$ MM btu/hr, $A = 4,304$ ft <sup>2</sup>	tubes - 75 psig, 200°F / shell - 15 psig, 200°F (single pass)	304 SS / C.S. w/corrosion allowance	\$56,000	\$92,566
E-527	dehydration vent condenser, $Q = 1$ MM btu/hr, $A = 150$ ft <sup>2</sup>	tubes - 75 psig, 200°F / shell - 15 psig, 200°F	304 SS / C.S. w/corrosion allowance	\$7,000	\$11,571
D-528	decanner, 14 ft dia x 15 ft high, dished top head, cone bottom w/skirt	15 psig, 100°F	304 SS	\$21,000	\$76,367



TABLE 5. Equipment List for Base Case Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
E-529	dehydration reflux cooler, Z = 8.4 MM btu/hr, A = 1,312 ft <sup>2</sup>	tubes - 30 psig, 200°F / shell - 75 psig, 200°F	304 SS / C.S.	\$38,000	\$62,813
P-530	stripper feed pump, centrifugal, 32 gpm, 93 ft TDH, 1.5 hp	100°F	D.I.	\$900	\$1,488
P-531	dehydration reflux pump, centrifugal, 600 gpm, 120 ft TDH, 25 hp	50 psig, 150°F	D.I.	\$1,400	\$2,314
T-532	hydrocarbon stripper, 42 in dia, 30 perforated trays	15 psig, 250°F	C.S. shell / C.S. trays	\$24,000	\$39,671
P-533	condenser/reboiler, condensate pump, centrifugal, 500 gpm, 40 ft TDH, 5 hp	75 psig, 300°F	304 SS	\$1,500	\$2,479
P-534	stripper reboiler pump, centrifugal, 120 gpm, 50 ft TDH 2.5 hp	20 psig, 250°F	304 SS	\$1,100	\$1,818
P-535	stripper reboiler condensate pump, centrifugal, 57 gpm, 40 ft TDH, 0.75 hp	75 psig, 300°F	D.I.	\$900	\$1,488
E-536	hydrocarbon stripper reboiler, Q = 6 MM btu/hr, A = 3,000 ft <sup>2</sup>	tubes - 75 psig, 300°F / shell - 15 psig, 250°F	304 SS / C.S.	\$66,000	\$109,096
E-537	fusel oil cooler, A = 50 ft <sup>2</sup>	tubes - 75 psig, 300°F / shell - 75 psig, 250°F	304 SS / C.S.	\$3,000	\$4,959
T-538	fusel oil washer, 24 in dia x 15 ft high, w/36 in dia x 24 in settling drum, skirt bottom	75 psig, 200°F	304 SS	\$2,200	\$8,000
P-539	wash water pump, centrifugal, 30 gpm, 115 ft TDH, 1 hp	150°F	D.I.	\$900	\$1,488
TK-540	fusel oil storage tank, nom cap = 5,000 gal, cone roof, flat bottom	atm., 150°F	C.S.	\$5,000	\$8,265
P-541	fusel oil pump, metering, 10 gpm, 150 ft TDH	150°F	D.I.	\$500	\$826
	Total Equipment, Section 500			\$1,475,900	\$3,343,525



TABLE 6. Equipment List for Base Case Technology  
Section 600 - Feed Processing

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
TK-600	whole stillage tank, 18 ft dia x 18 ft high, 15° cone top, flat bottom, nom cap = 33,000 gal	atm., 220°F	C.S.	\$32,100	\$53,060
AG-601	whole stillage agitator, 45 rpm, 50 hp		C.S.	\$14,900	\$24,629
P-602	whole stillage pump, centrifugal, 1200 gpm, 60 ft TDH, 30 hp	220°F	D.I.	\$2,200	\$3,637
CS-603 A to H	centrifugal separators, sharples P-5000 with instruments, 250 hp (each) ( 8 required)	220°F	304 SS	\$880,000	\$1,454,612
AG-604	thin stillage agitator, 45 rpm, 10 hp		C.S.	\$6,300	\$10,414
TK-605	thin stillage tank, 18 ft dia x 18 ft high, 15° cone top, flat bottom, nom cap = 33,000 gal	atm., 220°F	C.S.	\$32,100	\$53,060
P-606	think stillage pump, centrifugal, 1,100 gpm, 60 ft TDH, 30 hp	220°F	D.I.	\$2,200	\$3,637
E-607	evaporator feed heater, Q = 17.9 MM btu/hr, A = 4,000 ft <sup>2</sup>	50 psig, 220°F	C.S.	included w/ EV-612 to EV-615	
P-608	evaporator condensate pump, centrifugal, 950 gpm, 30 ft TDH, 15 hp	220°F	D.I.	\$1,750	\$2,893
TK-609	evaporator condensate tank, 16 ft dia x 16 ft high, 15° cone top, flat bottom, nom cap = 24,000 gal	atm., 220°F	C.S.	\$19,200	\$31,737
D-610	condensate level drum, 7 ft dia x 7 ft high, dished heads, nom cap = 2,000 gal	10 psig, 220°F	C.S.	included w/ EV-612 to EV-615	
CP-611	evaporator compressor, 15 psia inlet, 21 psia outlet, w/steam turbine drive, 6,200 hp		std.	included w/ EV-612 to EV-615	
EV-612 to 615	thin stillage evaporators, vapor recompression, total duty = 398,100 lbs/hr (4 required)	10 psig, 250°F	304	\$3,500,000	\$5,785,388
D-616	evaporator entrainment separator drums	10 psig, 250°F	304 SS	included w/ EV-612 to EV-615	



TABLE 6. Equipment List for Base Case Technology  
Section 600 - Feed Processing

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978) included w/ EV-612 to EV-615	Estimated Cost (1992)
P-620 to P-623	evaporator circulation pumps, centrifugal, 3,500 gpm (each), 35 ft TDH, 75 hp (each)	220°F	D.I.		
TK-624	concentrated solubles tank, 8-1/2 ft dia x 8-1/2 ft high, 15° cone top, flat bottom, nom cap = 3,500 gal	atm., 220°F	C.S.	\$4,400	\$7,273
P-625	concentrated solubles pump, centrifugal, 65 gpm, 50 ft TDH, 3 hp	250°F	D.I.	\$750	\$1,240
P-626	hot condensate pump, centrifugal, 950 gpm, 35 ft TDH, 15 hp	250°F	D.I.	\$1,750	\$2,893
E-627	evaporator vent condenser, Q = 2.7 MM btu/hr, A = 100 ft <sup>2</sup>	tubes - 100 psig, 150°F / shell - 10 psig, 250°F / channels & tube sheets	304 SS / C.S. / C.S.	\$5,000	\$8,265
E-628	air heater, Q = 10.86 MM btu/hr	tubes - 200 psig, 400°F	C.S. w/ aluminum fins	\$23,000	\$38,018
B-629 A/B/C	dry grains recycle blower, 1,000 cfm, 105 in w.c., 50 hp (each) (3 required)	atm., 100°F	std.	\$75,000	\$123,973
CC-630 A/B/C	cyclone collectors, 55,000 cfm (each)	30" vacuum, 200°F	Carpenter 20 clad	\$54,000	\$89,260
C-631 A/B/C	dry grains recycle conveyors, 20 ft long, 14 in dia, 3 hp (each), nom cap = 40,000 lbs/hr @ 25 lbs/ft <sup>3</sup> (3 required)	atm., 200°F	std.	\$12,500	\$20,662
C-632	wet cake transfer conveyor, 80 ft long, 12 in dia, 7.5 hp, nom cap = 52,500 lb/hr	atm., 200°F	std.	\$7,700	\$12,728
HM-633 A/B	dry grains product grinder, 150 hp (each) (2 required)	atm., 200°F	std.	\$24,100	\$39,837
E-634 A/B/C	dry grains product coolers, Q = 1.75 MM btu/hr, A = 1,080 ft <sup>2</sup> (each) (3 required)	atm., 200°F	Mild stl.	\$320,400	\$529,611
B-635	dry grains product transfer blower, 1,000 cfm, 180 in w.c., 100 hp			\$49,500	\$81,822
ML-636 A/B/C	wet grains mingler, 50 hp (each), nom cap = 70,000 lbs/hr (each) (3 required)	atm., 200°F	std.	\$57,150	\$94,467



TABLE 6. Equipment List for Base Case Technology  
Section 600 - Feed Processing

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
C-637 A/B/C	wet cake feed conveyors, 12 ft long, 9 in dia, 1 hp, nom cap = 17,500 lbs/hr (3 required)	atm., 200°F	std.	\$12,900	\$21,323
C-638 A/B/C	dryer feed conveyors, 20 ft long, 14 in dia, 5 hp (each), nom cap = 70,000 lb/hr (3 required)	atm., 600°F	std.	\$12,500	\$20,662
DR-639 A/B/C	spent grains dryer, nom cap = 70,000 lbs/hr (each) (3 required)	atm., 600°F	brick lined	\$810,000	\$1,338,904
FV-640 A/B/C	flue gas cyclone outlet valves (3 required)	atm., 250°F	316 SS	\$5,100	\$8,430
FV-641	bag filter outlet valve, nom cap = 165,000 lb/hr @ 25 lbs/ft3	atm., 200°F	std.	\$6,000	\$9,918
FV-642 A/B/C	dryer outlet valves (3 required)	5 psig, 250°F	316 SS	\$32,000	\$52,895
FV-643	product cooler outlet valve, nom cap = 45,000 lb/hr @ 25 lbs/ft3	atm., 100°F	std.	\$4,000	\$6,612
BH-644	bag filter house, nom cap = 12,600 cfm	5 psig, 100°F	std.	\$18,000	\$29,753
H-645	dry grains hopper, nom cap = 3,200 ft3, live bottom	atm.	std.	\$90,000	\$148,767
	Total Equipment, Section 600			\$6,116,500	\$10,110,379



TABLE 7. Equipment List for Base Case Technology  
Section 700 - Storage and Shipping

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
TK-701, TK-702	receiver tanks, 32-1/2 ft dia x 32-1/2 ft high, cone top, flat bottom, nom cap = 170,000 gal (2 required)	atm., amb.	C.S.	\$100,000	\$165,297
P-703 A/B	receiver pumps, 2,500 gpm, 100 ft TDH, 75 hp (each) (2 required)	30 psig, 100°F	304 SS	\$13,500	\$22,315
TK-704	gasoline storage tank, cone roof, flat bottom, nom cap = 50,000 gal	atm., amb.	C.S.	\$20,000	\$33,059
P-705	gasoline metering pump, 25 gpm, 100 ft TDH, 1 hp	30 psig, amb.	C.S.	\$1,000	\$1,653
TK-706 to TK-709	product storage tanks, 67 ft dia x 40 ft high, cone roof, flat bottom, nom cap = 1 MM gal (each) (4 required)	atm., amb.	C.S.	\$460,000	\$760,365
P-710	transfer pump, 2,500 gpm, 100 ft TDH, 60 hp	amb.	D.I.	\$6,000	\$9,918
DV-713	diverter valve, 6 in, air operated, plug type	100°F	std.	\$4,000	\$6,612
BF-715	bag filter, 1,000 cfm	100°F	std.	\$5,300	\$8,761
BF-716	bag filter, 4,000 cfm			\$6,000	\$9,918
FV-717	feeder valve, 16 in dia x 14 in, 40 rpm, 1.5 hp	atm., 100°F	std.	\$4,000	\$6,612
C-718	dry grains storage conveyor, 160 ft long, 14 in dia, 15 hp	100°F	std.	\$13,700	\$22,646
B-719	dry grain transfer blower, 3,000 cfm, 75 in w.c., 100 hp		std.	\$41,800	\$69,094
FV-720 A/B/C/D	feeder valve, 20 in dia x 18 in, 40 rpm, 2 hp (each) (4 required)	100°F	std.	\$24,000	\$39,671
FV-721	feeder valve, 24 in dia x 22 in, 32 rpm, 2 hp	100°F	std.	\$6,000	\$9,918
SB-722	shipping surge bin, 1,500 ft <sup>3</sup> , live bottom, 30 hp	100°F	std.	\$62,000	\$102,484
C-723	shipping conveyor, 20 ft long, 24 in dia, 7.5 hp	100°F	std.	\$5,000	\$8,265
SC-724	product truck scale, 50 T cap, 60 ft x 10 ft, Fairbanks model 12-3334		std.	\$25,000	\$41,324
SC-725	product car scale, 150 T cap, Fairbanks model 12-1304		std.	\$75,000	\$123,973
LT-726	loader tractor, 5 yd bucket			\$60,000	\$99,178
	Total Equipment, Section 700			\$932,300	\$1,541,062



TABLE 8. Equipment List for Base Case Technology  
Section 800 - Utilities

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
	<b>Boiler Components</b>				
C-801	coal storage conveyor, 75 ft long (drag), nom cap = 8.2 T/hr, 25° incline	outside atm. conditions	std.	\$3,500,000	\$5,785,388
UN-803	coal unloading station, 8.2 T/hr	outside atm. conditions	std.		
C-804	coal supply conveyor, 100 ft long, nom cap = 8.2 T/hr, 25° incline	outside atm. conditions	std.		
BL-805	coal fired boiler, 250,000 lbs/hr steam, 600°F, 600 psig, 725°F flue gas, 12.5 T coal/hr	650 psig, 600°F	std.		
BU-808	coal bunker, 25 ft x 15 ft 15 ft high, 100 T capacity	atm., amb.	C.S.		
SJ-892	ash pit ejector				
FL-828 A/B/C/D	coal feeders, 5 T/hr (each), Stoker-spreader type	std.	std.		
	<b>Boiler Auxiliaries Package</b>				
CC-806	cyclone collectors, multiclones, 9 in dia tubes (2 units required)	atm., 800°F	C.S.	\$500,000	\$826,484
P-809 A/B	boiler feedwater pumps, 450 gpm, 1,400 ft TDH, 250 hp (each)	600 psig, 220°F	casing-CI, Imp. CI, Sleeve 316 SS		
BF-827	ash bag filter, 2,000 acfm, cloth filters	atm., 150°F			
AC-807	ash collection package, vacuum pickup of ash w/steam ejector	200°F, 30" vacuum	tile lined		
TR-802	front end loader, 5 cu yd capacity	outside use	std.		
R-812	boiler water treatment/deaeration reactor package, 14 ft dia x 35 ft high	15 psig, 250°F	C.S.	\$40,000	\$66,119
	<b>Boiler Feed Water Package</b>				
TK-810	chemical mix tank, nom cap = 1,000 gal, flat top, 1 hp mixer	atm., 150°F	C.S.	\$120,000	\$198,356
P-811	boiler water chem treatment pump, 8 gpm, 50 ft TDH, 0.25 hp	150°F	D.I.		
P-813	filter backwash pump, centrifugal, 200 gpm, 30 ft TDH, 3 hp	250°F	D.I.		



TABLE 8. Equipment List for Base Case Technology  
Section 800 - Utilities

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
F-814 to F-816	anthracite filter, 6 ft 6 in dia, 4 ft high, dished heads (3 required)	15 psig, 250°F	C.S.		
R-818 to R-820	ion exchange reactors, 4 ft 6 in dia, 5 ft high, dished heads (3 required)	15 psig, 250°F	C.S.		
P-821 and P-822	booster pumps, 300 gpm, 40 ft TDH, 7.5 hp (each)	20 psig, 250°F	D.I.		
P-823	salt pump, centrifugal, 5 gpm, 30 ft TDH, 1/3 hp	150°F	316 SS		
TK-824	salt tank, 4 ft dia x 5 ft high	atm.	304 SS		
TK-825	boiler chemical mix tank, 3 ft dia x 4 ft high	atm., 150°F	C.S.		
P-826	chemical metering pump, 1 gpm, 1,400 ft TDH, 2 hp	150°F	C.S.		
	Total Boiler Related Equipment, Section 800-A				\$6,876,347
	<b>Fire Protection Package</b>				
TK-834	fire protection tank, nom cap = 300,000 gal, piping and hydrants	atm., amb.	C.S.	\$600,000	\$991,781
P-825 and P-836	electric fire pumps, centrifugal, 2,000 gpm, 325 ft TDH, 200 hp (each) (2 required)	atm., amb.	D.I.		
P-837 and P-838	diesel aux. fire pumps, centrifugal, 2,000 gpm, 225 ft TDH, 200 hp (each) (2 required)	atm., amb.	D.I.		
	<b>Wastewater Treatment Package</b>				
GT-838	grit trap	atm., amb.		\$2,000,000	\$3,305,936
TK-839	1st stage aeration tank, 95 ft dia x 25 ft high, w/agitation, 150 hp	atm., amb.	concrete		
TK-840	1st stage settling tank, 76 ft dia x 12 ft high	atm., amb.	concrete		
P-841 A/B	sludge pumps, 500 gpm, 50 ft TDH, 10 hp (each) (2 required)	amb.	316 SS		
TK-842	2nd stage aeration tank, 95 ft dia x 25 ft high, w/agitation, 150 hp	atm., amb.	concrete		
B-843 A/B/C	air blowers, 2,000 acfm, 400 hp (each)	atm., amb.	C.S.		



TABLE 8. Equipment List for Base Case Technology  
Section 800 - Utilities

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
TK-844	2nd stage settling tank, 76 ft dia x 12 ft high	atm., amb.	concrete		
P-845 A/B	sludge pumps, 500 gpm, 50 ft TDH, 10 hp (each) (2 required)	atm., amb.	316 SS		
TK-846	thickener tank, 20 ft dia x 10 ft high	atm., amb.	concrete		
P-847	thickener pump, 50 gpm, 1 hp	amb.	316 SS		
DW-848	dewatering press, 80 in twin wire, belt press	atm., amb.	std.		
TK-849	chlorine contact tank, 3 ft x 6 ft x 15 ft long	atm., amb.	C.S.		
TK-850	chlorine cylinders, std. equipment	atm., amb.	C.S.		
C-895	sludge conveyor, 8 in screw, 60 ft long	atm., 200°F	C.S.		
	<b>Cooling Tower Package</b>			\$500,000	\$826,484
CT-890	cooling tower, 32 ft x 46 ft x 59 ft high, pumping head = 35 ft, fan - 28 ft, 2 speed, 150 hp	atm., 120°F	treated hard redwood, frp piping, frp casing		
P-891 A/B/C	cooling tower pumps, centrifugal, 7,500 gpm (each), 150 ft TDH, 450 hp (P-891C is spare)	120°F	D.I.		
	<b>Electric Power Distribution Package</b>	11,000 KW		\$1,300,000	\$2,148,858
	<b>Total non-Boiler Equipment. Section 800-B</b>				\$7,273,059
	<b>Total Equipment, Sections 800-A and 800-B</b>			\$8,560,000	\$14,149,406



**TABLE 9**  
**Fixed Capital Cost Estimate for 50 Million Gallons per Year Ethanol**  
**Base Case Technology**

Section 100 - Grain Storage and Handling				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,628,008
2	Installed equipment cost	1	1.43	\$2,328,052
3	Process piping	2	0.07	\$162,964
4	Instrumentation	2	0.05	\$116,403
5	Buildings and site development	2	0.10	\$232,805
6	Auxiliaries	2	0.25	\$582,013
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,422,236
9	Engineering and construction	8	0.20	\$684,447
10	Contingencies	8	0.10	\$342,224
11	Size factor	8	0.02	\$68,445
12	Total fixed capital investment			\$4,517,352
Section 200 - Cooking and Saccharification				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,438,578
2	Installed equipment cost	1	1.43	\$2,057,167
3	Process piping	2	0.30	\$617,150
4	Instrumentation	2	0.10	\$205,717
5	Buildings and site development	2	0.20	\$411,433
6	Auxiliaries	2	0.25	\$514,292
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,805,758
9	Engineering and construction	8	0.20	\$761,152
10	Contingencies	8	0.10	\$380,576
11	Size factor	8	0.02	\$76,115
12	Total fixed capital investment			\$5,023,601
Section 400 - Fermentation				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$5,345,699
2	Installed equipment cost	1	1.43	\$7,644,349
3	Process piping	2	0.50	\$3,822,175
4	Instrumentation	2	0.05	\$382,217
5	Buildings and site development	2	0.10	\$764,435
6	Auxiliaries	2	0.25	\$1,911,087
7	Other	2	0.00	\$0
8	Total physical plant costs			\$14,524,263
9	Engineering and construction	8	0.20	\$2,904,853
10	Contingencies	8	0.10	\$1,452,426
11	Size factor	8	0.02	\$290,485
12	Total fixed capital investment			\$19,172,027



**TABLE 9**  
**Fixed Capital Cost Estimate for 50 Million Gallons per Year Ethanol**  
**Base Case Technology**

Section 500 - Distillation				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$3,343,525
2	Installed equipment cost	1	1.43	\$4,781,240
3	Process piping	2	0.60	\$2,868,744
4	Instrumentation	2	0.20	\$956,248
5	Buildings and site development	2	0.10	\$478,124
6	Auxiliaries	2	0.25	\$1,195,310
7	Other	2	0.00	\$0
8	Total physical plant costs			\$10,279,666
9	Engineering and construction	8	0.20	\$2,055,933
10	Contingencies	8	0.10	\$1,027,967
11	Size factor	8	0.02	\$205,593
12	Total fixed capital investment			\$13,569,159
Section 600 - Feed Processing				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$10,110,379
2	Installed equipment cost	1	1.43	\$14,457,842
3	Process piping	2	0.50	\$7,228,921
4	Instrumentation	2	0.10	\$1,445,784
5	Buildings and site development	2	0.10	\$1,445,784
6	Auxiliaries	2	0.25	\$3,614,460
7	Other	2	0.00	\$0
8	Total physical plant costs			\$28,192,792
9	Engineering and construction	8	0.20	\$5,638,558
10	Contingencies	8	0.10	\$2,819,279
11	Size factor	8	0.02	\$563,856
12	Total fixed capital investment			\$37,214,485
Section 700 - Storage and Shipping				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,541,062
2	Installed equipment cost	1	1.43	\$2,203,719
3	Process piping	2	0.30	\$661,116
4	Instrumentation	2	0.05	\$110,186
5	Buildings and site development	2	0.10	\$220,372
6	Auxiliaries	2	0.25	\$550,930
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,746,322
9	Engineering and construction	8	0.20	\$749,264
10	Contingencies	8	0.10	\$374,632
11	Size factor	8	0.02	\$74,926
12	Total fixed capital investment			\$4,945,145



**TABLE 9**  
**Fixed Capital Cost Estimate for 50 Million Gallons per Year Ethanol**  
**Base Case Technology**

Section 800-A - Boiler Related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$6,876,347
2	Installed equipment cost	1	1.00	\$6,876,347
3	Process piping	2	0.25	\$1,719,087
4	Instrumentation	2	0.10	\$687,635
5	Buildings and site development	2	0.20	\$1,375,269
6	Auxiliaries	2	0.25	\$1,719,087
7	Other	2	0.00	\$0
8	Total physical plant costs			\$12,377,425
9	Engineering and construction	8	0.20	\$2,475,485
10	Contingencies	8	0.10	\$1,237,742
11	Size factor	8	0.02	\$247,548
12	Total fixed capital investment			\$16,338,201
Section 800-B - Non-Boiler related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$7,273,059
2	Installed equipment cost	1	1.00	\$7,273,059
3	Process piping	2	0.25	\$1,818,265
4	Instrumentation	2	0.10	\$727,306
5	Buildings and site development	2	0.20	\$1,454,612
6	Auxiliaries	2	0.25	\$1,818,265
7	Other	2	0.00	\$0
8	Total physical plant costs			\$13,091,507
9	Engineering and construction	8	0.20	\$2,618,301
10	Contingencies	8	0.10	\$1,309,151
11	Size factor	8	0.02	\$261,830
12	Total fixed capital investment			\$17,280,789
Total fixed capital for sections 800-A and 800-B				\$33,618,990
Total				\$118,060,759



TABLE 10. Operating Cost  
 Corn based ethanol plant in Illinois, 1992  
 50 million gallons per year, 199° (99.5 wt %)  
 330 operating days per year  
 Base Case Technology - batch fermentation, distillation,  
 solvent dehydration, thin stillage evaporation and DDGS drying

Item	Annual Use	Units	Value Per	Unit	Annual Cost	Cost/Gal	% of Total
<b>A. MATERIALS</b>							
1. Corn, 56 lb/bu	1088	M lb/y	\$2.50	/bu	\$48,571,429	0.971	61.88%
2. Yeast	792	K lb/y	\$0.40	/lb	\$316,800	0.006	0.40%
3. Gasoline denaturant	285120	gal/y	\$0.60	/gal	\$171,072	0.003	0.22%
4. Ammonia	6.075	M lb/y	\$120.00	/ton	\$364,500	0.007	0.46%
5. Lime	1.584	M lb/y	\$40.00	/ton	\$31,680	0.001	0.04%
6. Sludge polymer	16	K lb/y	\$3.00	/lb	\$48,000	0.001	0.06%
7. BFW Chemicals	40	Klb/y	\$1.00	/lb	\$40,000	0.001	0.05%
8. NaCl	792	Klb/y	\$50.00	/ton	\$19,800	0.000	0.03%
9. enzymes	155000	gal/y	\$7.77	/gal	\$1,204,350	0.024	1.53%
<b>B. LABOR</b>							
1. operators	43	people	\$40,000	/y	\$1,720,000	0.034	2.19%
2. labors	54	people	\$25,000	/y	\$1,350,000	0.027	1.72%
3. technicians	8	people	\$35,000	/y	\$280,000	0.006	0.36%
4. maintenance	25	people	\$40,000	/y	\$1,000,000	0.020	1.27%
5. fringe benefit	25	%			\$1,087,500	0.022	1.39%
<b>C. ENERGY</b>							
1. Illinois #6 Coal	195.8	M lb/y	\$25.00	/ton	\$2,447,500	0.049	3.12%
2. Electricity	51,796,800	KWH/y	\$0.05	/KWH	\$2,589,840	0.052	3.30%
<b>D. CAPITAL</b>							
	Total Capital		% of Capital				
1. investment charges	\$118,060,759		11.11		\$13,116,550	0.262	16.71%
2. insurance			1.00		\$1,180,608	0.024	1.50%
3. maintenance			2.50		\$2,951,519	0.059	3.76%
<b>E. TOTAL</b>							
					\$78,491,148	1.570	100.00%
<b>F. CREDITS</b>							
	Annual Product		Value Per	Unit			
1. ddgs	346.8	M lb/y	\$120	/ton	\$20,808,000	0.416	26.51%
<b>G. NET COST</b>							
					\$57,683,148	1.154	73.49%



**TABLE 11. Operating Cost Sensitivity  
Base Case Technology**

Price Change in Item	Net Production Cost, \$/gal	Change in Net Production Cost per Indicated Price Change
<b>Corn Price, \$/bu</b>		
\$3.00	1.348	
\$2.75	1.251	
\$2.50	1.154	9.7c/gal per 25c/bu
\$2.25	1.057	
\$2.00	0.959	
<b>DDGS Price, \$/ton</b>		
\$80.00	1.292	
\$100.00	1.223	
\$120.00	1.154	6.9c/gal per \$20/ton
\$140.00	1.084	
\$160.00	1.015	
<b>Coal, \$/ton @ 10,630btu/lb</b>		
\$20.00	1.144	
\$25.00	1.154	
\$30.00	1.163	1.0c/gal per \$5/ton
\$35.00	1.173	
\$40.00	1.183	
\$45.00	1.193	
\$50.00	1.203	
<b>Electricity, c/KWH</b>		
2	1.123	
3	1.133	
4	1.143	1.0c/gal per 1c/KWH
5	1.153	
6	1.164	
7	1.174	
<b>% of Capital</b>		
110	1.188	
100	1.154	3.5c/gal per 10%increase
90	1.119	
<b>Ethanol Yield, gallon/bu</b>		
2.55	1.163	
2.57	1.154	
2.60	1.144	3.6c/gal per 0.1 gal/bu
2.65	1.126	
2.70	1.108	



## CHAPTER 3. BIOSTIL TECHNOLOGY

### BIOSTIL PROCESS FLOWSHEETS AND DESCRIPTIONS

Although Weatherly, Inc. prepared a full plant design from corn handling to utilities, we took the key sections of the process that are unique to the Biostil technology and altered the base case sections accordingly.

Conceptual flowsheets for each of the modified sections (Sections 200, 400, 500 and 600) are presented as drawings 345411-14 through 345411-17. Sections 100 and 700 remain the same as in the base case, while Section 800 A has a modified boiler. A section-by-section description from Weatherly of the process for manufacturing motor fuel grade alcohol from grain (corn) for the Biostil process alternative is given below.

#### Section 200 Mash Cooking and Saccharification

The front end of the mash cooking and saccharification unit for the Biostil process alternative is the same as that of the base case. The similarity on the front end is shown on Drawing 345411-14. Since the Biostil process requires a completely saccharified carbohydrate feedstock, modifications were made to the back end of Section 200 to provide for this, as shown on Drawings 345411-14 and 345411-15.

After Cooking, flash-cooling, and addition of enzyme, the partially liquified starch enters the first of two Liquifaction Tanks, TK-240. Final Liquifaction takes place in the second Liquifaction Tank, TK-243. The slurry is pumped via P-245 through Heat Exchanger E-249 where it is cooled to 140°F. Before the slurry enters the presaccharification tank the pH is adjusted to 4.2 - 4.5 by injection of concentrated sulfuric acid into the Teflon coated in-line static mixer. Enzyme 2 (amylglucosidase) is added in the presaccharification tank. The slurry is then fed by gravity to the first saccharification tank, where the breakdown of the dextrans to simple fermentable sugars begins. The saccharification unit consists of six stirred tanks in series with gravity flow between them. Full saccharification is necessary for the fermentation process and is normally completed in 24 hours. Saccharified substrate is pumped from the last saccharification tank to the fermentor via two heat exchanger steps. In the first step, which serves as a regenerative exchanger, the 140°F substrate is cooled by process liquid. At the same time the process liquid is preheated to about 120°F. To assure that no warm liquid enters the fermentor, the substrate is finally cooled to 90°F with cooling water in the trim cooler.

#### Section 400 Continuous Fermentation

The fermentation section of the grain motor fuel alcohol plant is shown on drawing 345411-16. The liquid substrate is pumped from the saccharification section and metered continuously into a single tank fermentor. Here the simple sugars are converted to ethanol and carbon dioxide in the presence of yeast, which promotes the reaction. A viable yeast growth and concentration is maintained by the addition of nutrients (such as urea) and continuous fermentor



aeration with the addition of air or oxygen. Air for the support of this living yeast population is supplied by low pressure blowers that provide air at a pressure sufficient to overcome the head of the liquid in the fermentor.

Fluctuations in the yeast count of  $\pm 30\%$  have little effect on overall fermentor productivity, and the residual fermentable sugar concentrations can usually be maintained below 0.2 wt.%. In spite of the high concentration of sugar in the fermentor feed, the alcohol concentration in the fermentor is controlled at approximately 8 to 10% (by volume) by continuous circulation of the fermentation mash through the upper section of the mash column. This method permits fermentation of very concentrated substrate and also minimizes the inhibition of yeast activity due to the presence of high ethanol concentrations.

The fermentor exhaust gases, which contain residual air, carbon dioxide created in the fermentor, ethanol, and volatiles, are scrubbed with fresh dilution water to recover ethanol. The overall ethanol yield is increased by approximately 1% by scrubbing the fermentor exhaust gases. The scrubber water including ethanol is mixed with the process liquid in the process liquid tank.

### Fermentor Cooling

Stable fermentation requires careful fermentor temperature control. For every pound of ethanol produced approximately 516 Btu of heat is generated. For the Biostil process, this excess heat is removed by the continuous circulation of the fermentor broth through an external plate heat exchanger. The optimum fermentation temperature is 90°F.

### Fiber Separation

The fermentor mash is pumped from the fermentor to a two stage fiber separation section. The first stage separation consists of a bent stationary screen that separates the fibers from the fermentor liquor, with the fiber free phase passing on to the yeast recycling station. The fiber phase is then fed to the second stage separation in which the fibers are first washed with recycled liquid to minimize yeast losses and then fed to a decanter separator. The fiber phase including fibers and other insoluble material from this second step is sent to the bottom part of the mash column where ethanol is stripped off and recovered in the top section of the column.

### Yeast Recovery and Recycle

The high yeast concentration is maintained in the fermentor by the separation/recovery and recycle of yeast from the fiber free fermentor mash. The fiber free fermentor mash from the bent screens is pumped to a set of centrifugal nozzle separators. Yeast is spun off in the heavy phase, collected, and returned to the fermentor. Washing of the yeast with sulfuric acid to prevent infections is not required in the Biostil process.



## Section 500 Distillation

The distillation section of the grain motor fuel alcohol plant is shown on drawing 345411-17. The de-yeasted mash from the yeast separation stage is preheated through the regenerative heat exchanger and fed to the two section mash still. This two section, or split mash column, is essential to the stability of the Biostil process.

After degassification (carbon dioxide separation), the mash enters the upper section of the column, in which 90% of the alcohol fed with the mash is continuously removed as ethanol vapor at a concentration of 38 wt.%.

The mash liquid stream flows downward through the upper portion of the column to the bottom tray of the upper section. This bottom tray is a special design tray (chimney tray) that allows vapor to pass upward from the lower stripping section of the column but does not allow liquid to flow into the stripping section. The liquid collected on this tray is called the weak mash or recycle.

The weak mash stream is collected and pumped through the regenerative heat exchanger to preheat the mash going to the mash column. A portion of the weak mash is then sent to the sludge separator where the proteins (suspended solids) are separated to purge them from the system. This heavy phase or sludge phase is mixed with the fiber phase from the second fiber separation stage, and the mixture is sent to the lower section, or stripping section, of the mash column. Water and ethanol are evaporated, or stripped, from the sludge phase mixture producing a concentrated stillage. The light or clarified effluent from the sludge separator is mixed with the rest of the weak mash recycle and then split into two streams. One stream is sent to the front end of the process where it provides the process water for flour mixing and dilution in the saccharification section. The second stream is recycled back to the fermentor after being cooled to 90°F in the trim cooler.

Concentrated stillage is pumped from the bottom of the mash column to the flash reboiler tank where the final stillage concentration takes place. Due to the high fouling nature of the stillage, the column is provided with three reboiler systems; two in service and one on standby. All the reboilers are equipped with a Cleaning-in-Place (CIP) system. Concentrated stillage (approximately 30% DS) is pumped with a positive displacement pump to the dryer feed tanks; which serve as a buffer between distillation and drying.

### Aldehyde (heads) Concentration

Aldehydes (heads) are concentrated in the aldehyde (heads) concentration that is provided in the very upper section of the mash column. The head vapors from this section are condensed in the mash column condensers. The condensed heads are then split into two streams, one stream enters the top of the aldehyde column and serves as reflux while the other stream is pumped through the aldehyde cooler to final aldehyde storage.



## Rectification

Ethanol vapors (38 wt.%) are drawn off at the top of the mash column via the knock-out drum where liquid is separated from ethanol vapor. The ethanol vapor is then condensed in the dehydration column reboiler. Liquified 38 wt.% ethanol is then sent to the rectification feed tank. The rectification feed pump pumps the ethanol liquid via the preheater to the rectification column, which operates at 65 psia pressure. Ethanol is concentrated to 93 wt.% in the rectification column. Ethanol vapors leaving the top of the rectification column are used to heat the mash column where they are also condensed.

Condensed ethanol vapors from the mash column reboiler are sent to the rectification reflux tank, where flashed vapors are sent to 40 wt.% ethanol condensers. Ethanol (93 wt.%) from the rectification reflux tank is pumped back to the top of the rectification column and a part is fed dehydration column.

Fusel oils are removed from an intermediate point in the rectification column and washed with fresh water in the fusel oil decanters. Lutter water is removed at the bottom. Portions of the fusel oils are later mixed with the anhydrous ethanol.

## Dehydration

Ethanol (93 wt.%) liquid from the rectification reflux pump is mixed in line with cyclohexane and the mixture enters the dehydration column. The dehydration column, which operates at atmospheric pressure, is heated by 38 wt.% ethanol vapor from the mash column. This means that the dehydration column reboiler also serves as a condenser for the 38 wt.% ethanol before it is sent to the rectification column. A mixture of ethanol/cyclohexane/water is taken off at the top of the column as vapor. This vapor is condensed in two overhead condensers and some of the liquid is recycled back to the column as reflux. The rest is mixed with liquid from the top of the recover column. The mixture is then sent to the cyclohexane decanter, where the light fraction (mainly cyclohexane) is mixed as previously mentioned with 93 wt.% ethanol from the rectification section. The heavy phase is sent to the recovery column. The 99.5 wt.% ethanol is taken off from the bottom of the hydration column and pumped to ethanol day storage after being cooled in the ethanol cooler.

Samples will be taken from the ethanol day tank to check the quality before ethanol is sent to main storage tanks. The heavy phase from the cyclohexane decanter enters the recovery column, where the cyclohexane will be recovered and 80 wt.% ethanol is collected in the bottom of the column and from there transported to the mixing tank. In the mixing tank the ethanol/water mixture is mixed with liquid from the fusel oil decanters before entering the rectification column.

The recovery column is heated with steam.



## Section 600 Drying of Stillage Residue

The major impact of the Biostil process is that no thin stillage evaporator and centrifuges are needed in Section 600 of the base case. Only the second part of the original Section 600 is needed - namely the rotary drier shown in Drawing 345411-08.

## Section 800 - Boiler

Since the Biostil process does not require a thin stillage evaporator and its associate turbine driven vapor compressor, the boiler for the plant can operate at low pressure. The steam is needed only for process heating in distillation and starch cooking, 175,000 lb/h. In addition, the still bottoms are dried in a rotary drier using steam as a heating source, 117,000 lb/h. Thus, the total low pressure steam required is 292,000 lb/h which compares with 200,000 lb/h for the base case. The reason for this increase in steam load is that the rotary drier is higher in the Biostil case because the total solids come into the drying step at 30% solids where as in the base case, the concentrated thin stillage and wet fiber cake have a combined solid content of about 40%. Also in the base case, hot flue gas was used as part of the drying medium which will reduce the steam requirement. Detailed process optimization on the drying was not done in this study.

In order to supply the low pressure steam, packaged boilers are used. The cost is less because they are factory built and use natural gas or fuel oil instead of coal. Thus, there are no solids handling, particulate removal from the flue gas, and stokers. With a thermal efficiency of 90% the amount of natural gas is  $292,000 \text{ btu/h} \div .9$  or 324,000 btu/h. This is equivalent to 51.3 btu/gallon of ethanol produced.

The electrical load in the Biostil process is 12000 KW compared to 6540 KW. The major reason for the increase is on the operation of the centrifuges and recirculation pumps associated with the continuous fermentor. It should be noted that the energy usage in the Biostil case was taken on the conservative side. With an actual plant design optimized on corn fermentation, we can see reductions to levels closer to the base case.

## Capital Cost

The equipment lists for Section 200, 400, 500, 600 and 800 are given in Tables 12 through 18 along with the delivered cost for each section at the end of each table.

The fixed capital for the Biostil process is given in Table 17 by developing the fixed cost of each section. Sections 100 and 700 are taken directly from the base case since these are the same in the two designs.

## Operating Cost

The operating costs are given in Table 18. The material costs are the same as the base case except there is no yeast charge due to the reuse of yeast.



There is a significant reduction of labor in all categories. The main reason for this is that the continuous fermentation and coupled distillation is highly automated. Moreover, the plant design has an automatic cleaning-in-place system to clean heat exchangers and centrifuges. Also, the absence of the thin stillage evaporation saves operating and maintenance labor.

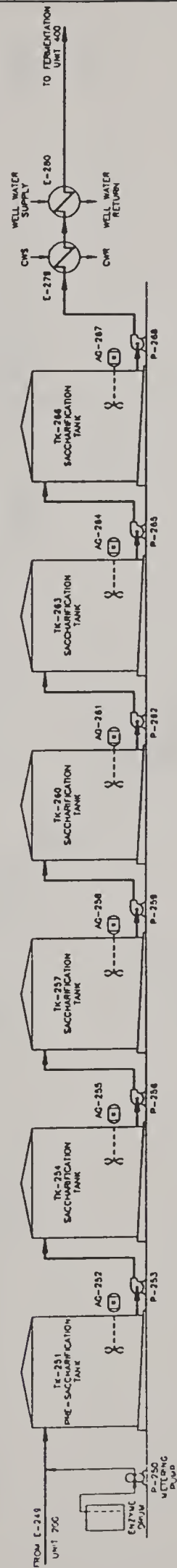
The energy costs are for natural gas which is burned in the packaged boiler and electricity. These costs are higher than in the base case.

The net operating cost is less than in the base case because of lower capital and labor costs. The sensitivity to the energy cost is given in Table 19.





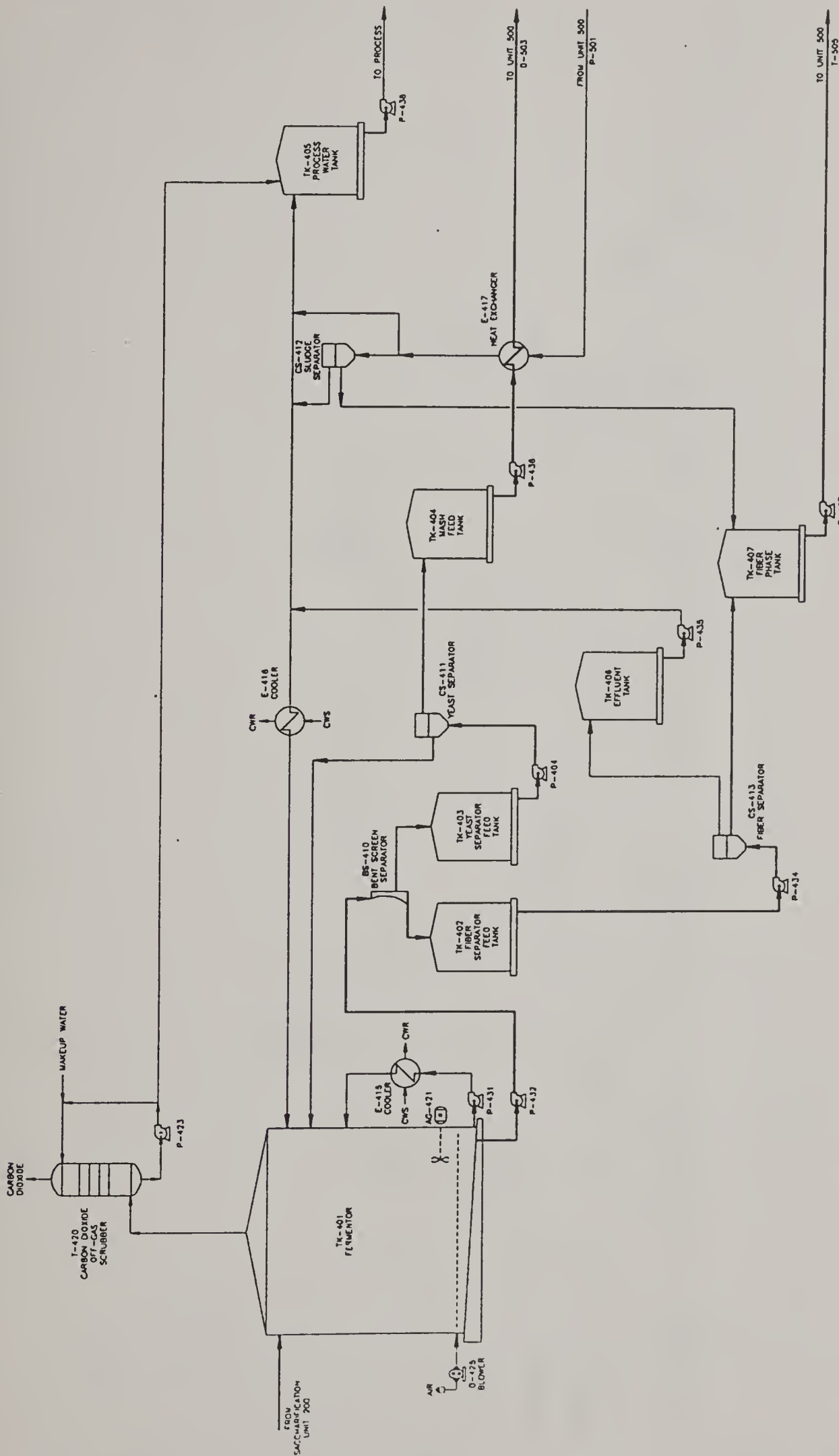




## SECTION 200 - COOKING AND SACCHARIFICATION FOR BIOSTIL

 MBI Engineering Inc.	DATE 7/1/82	REGION
	DATE	
	PROJECT NO. 34-5411	
	SER. NO. 345411-15	

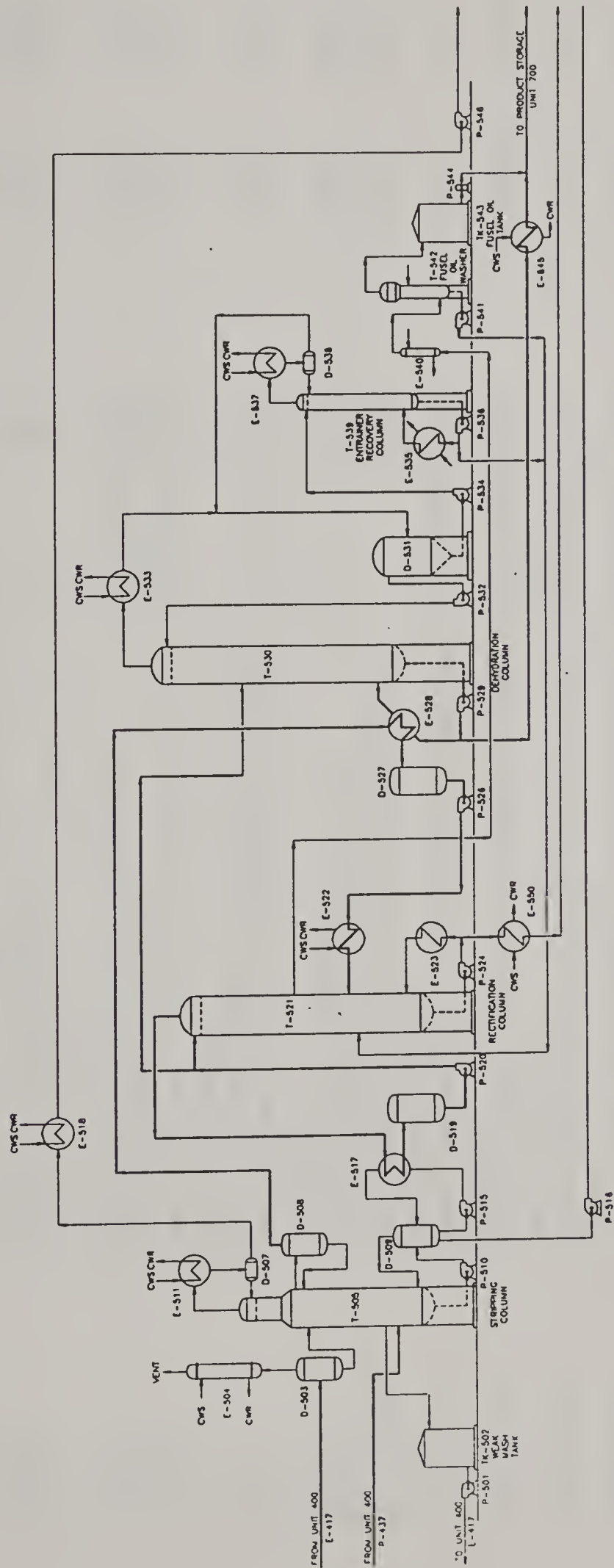




SECTION 400 - FERMENTATION FOR BIOSTIL

	DWG. BY	TBH	DATE	7/1/92	REVISION
	CHECKED BY		DATE		
	PROJECT NO.	34-5411			
	SAC. NO.	345411-16			





SECTION 500 - DISTILLATION AND DEHYDRATION FOR BIOSTIL

DESIGN BY	DATE	REVISION
BY	DATE	
PROJECT NO.	34-5411	
SHEET NO.	34-5411-17	

**mbi**  
Mitsubishi Engineering & Chemicals Inc.



**TABLE 12. Equipment List for Biostil Technology**  
**Section 200 - Cooking and Saccharification**

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
CC-201	meal cyclone collector	3900 acfm	std.	\$2,500	\$4,132
TK-202	meal surge tank (including scale), 7 ft dia x 7 ft side, cone bottom, 7,000 lb cap	amb.	C.S.	\$8,000	\$13,224
FV-203A/B	rotary feeder valve, 24 in x 22 in rotor, 31 rpm, 2 hp (2 required)	8,500 ft <sup>3</sup> /hr	std.	\$11,200	\$18,513
TK-204	batch weight tank, 9 ft x 9 ft side, cone bottom, 14,000 lb cap	amb.	C.S.	\$5,300	\$8,761
SV-205	slide valve, air operated, 24 in size		std.	\$1,000	\$1,653
TK-206	continuous weigh tank, 18 ft dia x 18 ft straight side, cone bottom (including scale)	amb.	C.S.	\$46,100	\$76,202
FV-207	rotary feeder valve, 24 in x 22 rotor, 31 rpm, 2 hp	4,250 ft <sup>3</sup> /hr	std.	\$5,600	\$9,257
AG-208	mixing tank agitator, 84 rpm, 15 hp		C.S.	\$4,500	\$7,438
TK-209	mash mixing tank, 7 ft 6 in dia x 7 ft 6 in, straight side, cone bottom, 2,500 gal cap	atm. 200°F	C.S.	\$3,200	\$5,289
P-210	mash mixer pump, centrifugal, 1000 gpm, 50 ft TDH, 30 hp		d.i.	\$2,200	\$3,637
TK-211	mash pre-cooker, 10 ft dia x 10 ft straight side, cone bottom, 6,500 gal cap	atm. 200°F	C.S.	\$7,000	\$11,571
AG-212	pre-cooker agitator, 84 rpm, 25 hp		C.S.	\$5,500	\$9,091
P-213	pre-cooker pump, 1,000 gpm, 400 ft TDH, 200 hp		d.i.	\$14,000	\$23,142
PLR-214A/B	mash cookers, 9-20 ft long x 10 in, sch 40 pipes, 2/8-180° return bends (2 required)		C.S.	\$16,200	\$26,778
TK-215A/B	pressure flash tank, 6 ft dia x 8 ft straight side, dished heads (2 required)	25 psig 300°F	C.S.	\$10,400	\$17,191
TK-216A/B	vacuum flash tank, 7 ft 6 in dia x 10 ft, straight side, dished heads (2 required)	full vacuum, 200°F	C.S.	\$19,800	\$32,729
SR-217A/B	pressure flash entrainment separator, 30,000 lb/hr steam @ 15 psig	25 psig, 300°F	C.S.	\$11,200	\$18,513
SR-218A/B	vacuum flash entrainment separator, 15,000 lb/hr steam @ 3.3 psia	full vacuum, 200°F	C.S.	\$13,200	\$21,819
P-219	fungal amylase mash pump, 150 gpm, 30 ft TDH, 5 hp		d.i.	\$1,100	\$1,818
MX-220A/B	fungal amylase mixer, 48 in dia x 90 in long, w/15 hp agitator (2 required)	full vacuum	C.S.	\$16,600	\$27,439



TABLE 12. Equipment List for Biostil Technology  
Section 200 - Cooking and Saccharification

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
E-224	flash vapor condenser, Q=28.2MM btu/hr, A=4,170 ft <sup>2</sup>	full vacuum, 150 psig, 220°F, shell side	304 SS tubes, C.S. shell	\$75,000	\$123,973
EJ-225	steam ejector, 90 lb/hr motive steam @ 150 psig	30 lb/hr, air-3.3 psia	std.	\$800	\$1,322
E-226	ejector condenser, Q=0.1MM btu/hr, A=10 ft <sup>2</sup>	150 psig, 400°F	C.S shell, 304 SS tubes	\$800	\$1,322
TK-227	hot well, 5 ft dia x 5 ft high, flat bottom, loose cover	1 atm., 220°F	C.S.	\$1,400	\$2,314
P-228	hot well pump, 200 gpm, 30 ft TDH, 5 hp		d.i.	\$1,100	\$1,818
E-229	mash heater, Q=33.8MM btu/hr, A=4,400 ft <sup>2</sup>	25 psig, 300°F	C.S. shell, 304 SS tubes	\$80,000	\$132,237
	The following equipment is added to the base case to give a 24 hour saccharification time to insure complete hydrolysis of the starch. All wetted parts are 304 SS.				
TK-230	condensate flash tank, 2 ft dia x 3 ft, straight side	1 atm., 220°F	C.S.	\$300	\$496
TK-240	liquifaction tank				
AG-241	liquifaction tank agitator				
P-242	liquifaction tank pump				
TK-243	liquifaction tank				
AG-244	liquifaction tank agitator				
P-242	liquifaction tank pump				
E-249	liquifaction cooler				
P-250	enzyme metering pump				
TK-251	pre-saccharification tank				
AG-252	pre-saccharification tank agitator				
P-253	pre-saccharification tank pump				
TK-254	saccharification tank no. 1				
AG-255	saccharification tank no. 1 agitator				
P-256	saccharification tank no. 1 pump				
TK-257	saccharification tank no. 2				



TABLE 12. Equipment List for Biostil Technology  
Section 200 - Cooking and Saccharification

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
AG-258	saccharification tank no. 2 agitator				
P-259	saccharification tank no. 2 pump				
TK-260	saccharification tank no. 3				
AG-261	saccharification tank no. 3 agitator				
P-262	saccharification tank no. 3 pump				
TK-263	saccharification tank no. 4				
AG-264	saccharification tank no. 4 agitator				
P-265	saccharification tank no. 4 pump				
TK-266	saccharification tank no. 5				
AG-267	saccharification tank no. 5 agitator				
P-268	saccharification tank no. 5 pump				
E-279	feed cooler				
E-280	feed cooler				
	Total Equipment, Section 200 based on information from Weatherly, Inc.				\$2,700,000



TABLE 13. Equipment List for Biostill Technology  
Section 400 - Fermentation

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1992)
B-425	air blower			
TK-401	fermentor			
AG-421	agitator			
T-420	CO2 scrubber			
P-432	fermentor discharge pump			
P-431	fermentor cooling pump			
E-415	fermentor cooler			
BS-410	bent screens			
TK-402	fiber separation feed tank			
TK-403	yeast separator feed tank			
P-404	yeast separator feed pump			
P-434	fiber separator feed pump			
CS-413	fiber separator			
TK-407	fiber phase tank			
TK-406	fiber separator effluent tank			
P-435	fiber separator effluent pump			
P-437	fiber phase pump			
CS-411	yeast separator			
TK-404	mash column feed tank			
P-436	mash column feed pump			
E-417	regenerative heat exchanger			
CS-412	sludge separator			
TK-405	recycle tank			
E-416	trim cooler			
P-438	recycle pump			
	Total Equipment, Section 400 based on information from Weatherly, Inc.			\$7,450,000



TABLE 14. Equipment List for Biostil Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1992)
T-505	stripper column			
T-521	rectification column			
P-501	recycle pump			
TK-502	recycle tank			
D-503	CO2 separator			
E-517	mash column reboiler			
D-509	reboiler flash tank			
P-510	mash column bottoms pump			
P-515	mash column reboiler pump			
E-511	mash column condenser			
P-526	rectification feed pump			
D-519	rectification reflux tank			
P-520	rectification reflux pump			
P-516	lutter water pump			
E-523	rectification reboiler			
E-540	fusel oil cooler			
T-542	fusel oil washer			
P-541	fusel oil return pump			
P-544	fusel oil transfer pump			
P-529	desorption recycle pump			
E-550	lutter water cooler			
D-508	knock-out drum			
E-522	rectification feed preheater			
D-527	rectification feed tank			
T-530	dehydration column			
T-539	recovery column			
E-528	dehydration column reboiler			
E-535	recovery column reboiler			
E-533	dehydration column condenser			
E-537	recovery column condenser			
D-531	cyclohexane decanter			



TABLE 14. Equipment List for Biostil Technology  
Section 500 - Distillation and Dehydration

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1992)
P-532	cyclohexane pump			
P-529	99.5 wt. % ethanol pump			
E-545	ethanol cooler			
	Total Equipment, Section 500 based on information from Weatherly, Inc.			\$6,950,000



TABLE 15. Equipment List for Biostil Technology  
Section 600 - Feed Processing

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
E-628	air heater, Q = 10.86 MM btu/hr	tubes - 200 psig, 400°F	C.S. w/ aluminum fins	\$23,000	\$38,018
B-629 A/B/C	jdry grains recycle blower, 1,000 cfm, 105 in w.c., 50 hp (each) (3 required)	atm., 100°F	std.	\$75,000	\$123,973
CC-630 A/B/C	cyclone collectors, 55,000 cfm (each)	30" vacuum, 200°F	Carpenter 20 clad	\$54,000	\$89,260
C-631 A/B/C	dry grains recycle conveyors, 20 ft long, 14 in dia, 3 hp (each), nom cap = 40,000 lbs/hr @ 25 lbs/ft <sup>3</sup> (3 required)	atm., 200°F	std.	\$12,500	\$20,662
C-632	wet cake transfer conveyor, 80 ft long, 12 in dia, 7.5 hp, nom cap = 52,500 lb/hr	atm., 200°F	std.	\$7,700	\$12,728
HM-633 A/B	dry grains product grinder, 150 hp (each) (2 required)	atm., 200°F	std.	\$24,100	\$39,837
E-634 A/B/C	dry grains product coolers, Q = 1.75 MM btu/hr, A = 1,080 ft <sup>2</sup> (each) (3 required)	atm., 200°F	Mild stl.	\$320,400	\$529,611
B-635	dry grains product transfer blower, 1,000 cfm, 180 in w.c., 100 hp			\$49,500	\$81,822
ML-636 A/B/C	wet grains mingler, 50 hp (each), nom cap = 70,000 lbs/hr (each) (3 required)	atm., 200°F	std.	\$57,150	\$94,467
C-637 A/B/C	wet cake feed conveyors, 12 ft long, 9 in dia, 1 hp, nom cap = 17,500 lbs/hr (3 required)	atm., 200°F	std.	\$12,900	\$21,323
C-638 A/B/C	dryer feed conveyors, 20 ft long, 14 in dia, 5 hp (each), nom cap = 70,000 lb/hr (3 required)	atm., 600°F	std.	\$12,500	\$20,662
DR-639 A/B/C	spent grains dryer, nom cap = 70,000 lbs/hr (each) (3 required)	atm., 600°F	brick lined	\$810,000	\$1,338,904
FV-640 A/B/C	flue gas cyclone outlet valves (3 required)	atm., 250°F	316 SS	\$5,100	\$8,430
FV-641	bag filter outlet valve, nom cap = 165,000 lb/hr @ 25 lbs/ft <sup>3</sup>	atm., 200°F	std.	\$6,000	\$9,918
FV-642 A/B/C	dryer outlet valves (3 required)	5 psig, 250°F	316 SS	\$32,000	\$52,895
FV-643	product cooler outlet valve, nom cap = 45,000 lb/hr @ 25 lbs/ft <sup>3</sup>	atm., 100°F	std.	\$4,000	\$6,612
BH-644	bag filter house, nom cap = 12,600 cfm	5 psig, 100°F	std.	\$18,000	\$29,753
H-645	dry grains hopper, nom cap = 3,200 ft <sup>3</sup> , live bottom	atm.	std.	\$90,000	\$148,767
	Total Equipment, Section 600			\$1,613,850	\$2,667,642



TABLE 16. Equipment List for Biostil Technology Section 800 - Utilities						
Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)	
	<b>Boiler Components</b>				\$1,500,000	
	Packaged Boiler, natural gas fuel	200,000 lb/h 50 psig				
R-812	boiler water treatment/deaeration reactor package, 14 ft dia x 35 ft high	15 psig, 250°F	C.S.	\$40,000	\$66,119	
	<b>Boiler Feed Water Package</b>					
TK-810	chemical mix tank, nom cap = 1,000 gal, flat top, 1 hp mixer	atm., 150°F	C.S.	\$120,000	\$198,356	
P-811	boiler water chem treatment pump, 8 gpm, 50 ft TDH, 0.25 hp	150°F	D.I.			
P-813	filter backwash pump, centrifugal, 200 gpm, 30 ft TDH, 3 hp	250°F	D.I.			
F-814 to F-816	anthracite filter, 6 ft 6 in dia, 4 ft high, dished heads (3 required)	15 psig, 250°F	C.S.			
R-818 to R-820	ion exchange reactors, 4 ft 6 in dia, 5 ft high, dished heads (3 required)	15 psig, 250°F	C.S.			
P-821 and P-822	booster pumps, 300 gpm, 40 ft TDH, 7.5 hp (each)	20 psig, 250°F	D.I.			
P-823	salt pump, centrifugal, 5 gpm, 30 ft TDH, 1/3 hp	150°F	316 SS			
TK-824	salt tank, 4 ft dia x 5 ft high	atm.	304 SS			
TK-825	boiler chemical mix tank, 3 ft dia x 4 ft high	atm., 150°F	C.S.			
P-826	chemical metering pump, 1 gpm, 1,400 ft TDH, 2 hp	150°F	C.S.			
	Total boiler Related Equipment, Section 800-A				\$1,764,475	
	<b>Fire Protection Package</b>					
TK-834	fire protection tank, nom cap = 300,000 gal, piping and hydrants	atm., amb.	C.S.	\$600,000	\$991,781	
P-825 and P-836	electric fire pumps, centrifugal, 2,000 gpm, 325 ft TDH, 200 hp (each) (2 required)	atm., amb.	D.I.			
P-837 and P-838	diesel aux. fire pumps, centrifugal, 2,000 gpm, 225 ft TDH, 200 hp (each) (2 required)	atm., amb.	D.I.			



TABLE 16. Equipment List for Biostil Technology  
Section 800 - Utilities

Equip. ID	Description	Design Conditions	Materials of Construction	Estimated Cost (1978)	Estimated Cost (1992)
	<b>Wastewater Treatment Package</b>				
GT-838	grit trap	atm., amb.		\$2,000,000	\$3,305,936
TK-839	1st stage aeration tank, 95 ft dia x 25 ft high, w/agitation, 150 hp	atm., amb.	concrete		
TK-840	1st stage settling tank, 76 ft dia x 12 ft high	atm., amb.	concrete		
P-841 A/B	sludge pumps, 500 gpm, 50 ft TDH, 10 hp (each) (2 required)	amb.	316 SS		
TK-842	2nd stage aeration tank, 95 ft dia x 25 ft high, w/agitation, 150 hp	atm., amb.	concrete		
B-843 A/B/C	air blowers, 2,000 acfm, 400 hp (each)	atm., amb.	C.S.		
TK-844	2nd stage settling tank, 76 ft dia x 12 ft high	atm., amb.	concrete		
P-845 A/B	sludge pumps, 500 gpm, 50 ft TDH, 10 hp (each) (2 required)	atm., amb.	316 SS		
TK-846	thickener tank, 20 ft dia x 10 ft high	atm., amb.	concrete		
P-847	thickener pump, 50 gpm, 1 hp	amb.	316 SS		
DW-848	dewatering press, 80 in twin wire, belt press	atm., amb.	std.		
TK-849	chlorine contact tank, 3 ft x 6 ft x 15 ft long	atm., amb.	C.S.		
TK-850	chlorine cylinders, std. equipment	atm., amb.	C.S.		
C-895	sludge conveyor, 8 in screw, 60 ft long	atm., 200°F	C.S.		
	<b>Cooling Tower Package</b>				
CT-890	cooling tower, 32 ft x 46 ft x 59 ft high, pumping head = 35 ft, fan - 28 ft, 2 speed, 150 hp	atm., 120°F	treated hard redwood, frp	\$500,000	\$826,484
P-891 A/B/C	cooling tower pumps, centrifugal, 7,500 gpm (each), 150 ft TDH, 450 hp (P-891C is spare)	120°F	D.I.		
	<b>Electric Power Distribution Package</b>				
	Total non-Boiler equipment, Section 800-B	11,000 KW		\$1,300,000	\$2,148,858
					\$7,273,059
	Total Equipment, Section 800			\$4,560,000	\$9,037,534



**TABLE 17**  
**Fixed Capital Cost Estimate for 50 Million Gallons Per Year**  
**Fuel Grade Ethanol From Corn Biostil Technology**

Section 100 - Grain Storage and Handling				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,628,008
2	Installed equipment cost	1	1.43	\$2,328,052
3	Process piping	2	0.07	\$162,964
4	Instrumentation	2	0.05	\$116,403
5	Buildings and site development	2	0.10	\$232,805
6	Auxiliaries	2	0.25	\$582,013
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,422,236
9	Engineering and construction	8	0.20	\$684,447
10	Contingencies	8	0.10	\$342,224
11	Size factor	8	0.02	\$68,445
12	Total fixed capital investment			\$4,517,352
Section 200 - Cooking and Saccharification				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$2,700,000
2	Installed equipment cost	1	1.43	\$3,861,000
3	Process piping	2	0.30	\$1,158,300
4	Instrumentation	2	0.10	\$386,100
5	Buildings and site development	2	0.20	\$772,200
6	Auxiliaries	2	0.25	\$965,250
7	Other	2	0.00	\$0
8	Total physical plant costs			\$7,142,850
9	Engineering and construction	8	0.20	\$1,428,570
10	Contingencies	8	0.10	\$714,285
11	Size factor	8	0.02	\$142,857
12	Total fixed capital investment			\$9,428,562
Section 400 - Fermentation				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$7,450,000
2	Installed equipment cost	1	1.43	\$10,653,500
3	Process piping	2	0.50	\$5,326,750
4	Instrumentation	2	0.05	\$532,675
5	Buildings and site development	2	0.10	\$1,065,350
6	Auxiliaries	2	0.25	\$2,663,375
7	Other	2	0.00	\$0
8	Total physical plant costs			\$20,241,650
9	Engineering and construction	8	0.20	\$4,048,330
10	Contingencies	8	0.10	\$2,024,165
11	Size factor	8	0.02	\$404,833
12	Total fixed capital investment			\$26,718,978



**TABLE 17**  
**Fixed Capital Cost Estimate for 50 Million Gallons Per Year**  
**Fuel Grade Ethanol From Corn Biostil Technology**

Section 500 - Distillation				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$6,950,000
2	Installed equipment cost	1	1.43	\$9,938,500
3	Process piping	2	0.60	\$5,963,100
4	Instrumentation	2	0.20	\$1,987,700
5	Buildings and site development	2	0.10	\$993,850
6	Auxiliaries	2	0.25	\$2,484,625
7	Other	2	0.00	\$0
8	Total physical plant costs			\$21,367,775
9	Engineering and construction	8	0.20	\$4,273,555
10	Contingencies	8	0.10	\$2,136,778
11	Size factor	8	0.02	\$427,356
12	Total fixed capital investment			\$28,205,463
Section 600 - Feed Processing				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$2,667,642
2	Installed equipment cost	1	1.43	\$3,814,729
3	Process piping	2	0.50	\$1,907,364
4	Instrumentation	2	0.10	\$381,473
5	Buildings and site development	2	0.10	\$381,473
6	Auxiliaries	2	0.25	\$953,682
7	Other	2	0.00	\$0
8	Total physical plant costs			\$7,438,721
9	Engineering and construction	8	0.20	\$1,487,744
10	Contingencies	8	0.10	\$743,872
11	Size factor	8	0.02	\$148,774
12	Total fixed capital investment			\$9,819,112
Section 700 - Storage and Shipping				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,541,062
2	Installed equipment cost	1	1.43	\$2,203,719
3	Process piping	2	0.30	\$661,116
4	Instrumentation	2	0.05	\$110,186
5	Buildings and site development	2	0.10	\$220,372
6	Auxiliaries	2	0.25	\$550,930
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,746,322
9	Engineering and construction	8	0.20	\$749,264
10	Contingencies	8	0.10	\$374,632
11	Size factor	8	0.02	\$74,926
12	Total fixed capital investment			\$4,945,145



TABLE 17 Fixed Capital Cost Estimate for 50 Million Gallons Per Year Fuel Grade Ethanol From Corn Biostil Technology				
Section 800-A - Boiler Related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,764,475
2	Installed equipment cost	1	1.00	\$1,764,475
3	Process piping	2	0.25	\$441,119
4	Instrumentation	2	0.10	\$176,447
5	Buildings and site development	2	0.20	\$352,895
6	Auxiliaries	2	0.25	\$441,119
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,176,055
9	Engineering and construction	8	0.20	\$635,211
10	Contingencies	8	0.10	\$317,605
11	Size factor	8	0.02	\$63,521
12	Total fixed capital investment			\$4,192,392
Section 800-B - Non-Boiler Related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$7,273,059
2	Installed equipment cost	1	1.00	\$7,273,059
3	Process piping	2	0.25	\$1,818,265
4	Instrumentation	2	0.10	\$727,306
5	Buildings and site development	2	0.20	\$1,454,612
6	Auxiliaries	2	0.25	\$1,818,265
7	Other	2	0.00	\$0
8	Total physical plant costs			\$13,091,507
9	Engineering and construction	8	0.20	\$2,618,301
10	Contingencies	8	0.10	\$1,309,151
11	Size factor	8	0.02	\$261,830
12	Total fixed capital investment			\$17,280,789
Total fixed capital for sections 800-A and 800-B				\$21,473,181
Total				\$105,107,793



TABLE 18. Operating Cost  
 Corn based ethanol plant in Illinois, 1992  
 50 million gallons per year, 199° (99.5 wt %)  
 330 operating days per year  
 Biostil Technology - continuous fermentation, distillation, solvent  
 dehydration and DDGS drying

Item	Annual Use	Units	Value Per	Unit	Annual Cost	Cost/Gal	% of Total
<b>A. MATERIALS</b>							
1. Corn, 56 lb/bu	1088	M lb/y	\$2.50	/bu	\$48,571,429	0.971	63.83%
2. Enzymes	155000	gal/y	\$7.77	/gal	\$1,204,350	0.024	1.58%
3. Gasoline denaturant	285120	gal/y	\$0.60	/gal	\$171,072	0.003	0.22%
4. Ammonia	6.075	M lb/y	\$120.00	/ton	\$364,500	0.007	0.48%
5. Lime	1.584	M lb/y	\$40.00	/ton	\$31,680	0.001	0.04%
6. Sludge polymer	16	K lb/y	\$3.00	/lb	\$48,000	0.001	0.06%
7. BFW Chemicals	40	Klb/y	\$1.00	/lb	\$40,000	0.001	0.05%
8. NaCl	792	Klb/y	\$50.00	/ton	\$19,800	0.000	0.03%
<b>B. LABOR</b>							
1. operators	17	people	\$40,000	/y	\$680,000	0.014	0.89%
2. labors	10	people	\$25,000	/y	\$250,000	0.005	0.33%
3. technicians	5	people	\$35,000	/y	\$175,000	0.004	0.23%
4. maintenance	6	people	\$40,000	/y	\$240,000	0.005	0.32%
5. fringe benefit	25	%			\$336,250	0.007	0.44%
<b>C. ENERGY</b>							
Natural Gas	2,566,000	M btu/y	\$1.50	/M btu	\$3,849,000	0.077	5.06%
2. Electricity	95,040,000	KWH/y	\$0.05	/KWH	\$4,752,000	0.095	6.25%
<b>D. CAPITAL</b>							
	Total Investment		% of Capital				
1. investment charges	\$105,107,793		11.11		\$11,677,476	0.234	15.35%
2. insurance			1.00		\$1,051,078	0.021	1.38%
3. maintenance			2.50		\$2,627,695	0.053	3.45%
<b>E. TOTAL</b>							
					\$76,089,329	1.522	100.00%
<b>F. CREDITS</b>							
	Annual Product		Value Per	Unit			
1. ddgs	346.8	M lb/y	\$120	/ton	\$20,808,000	0.416	27.35%
<b>G. NET COST</b>							
					\$55,281,329	1.106	72.65%



**TABLE 19. Operating Cost Sensitivity  
Biostil Technology**

<b>Price Change in Item</b>	<b>Net Production Cost, \$/gal</b>	<b>Change in Net Production Cost per Indicated Price Change</b>
<b>Natural Gas, \$/Mbtu</b>		
\$1.50	1.106	
\$2.00	1.131	2.6c/gal per 50c/Mbtu
\$2.50	1.157	
\$3.00	1.183	
<b>Electricity, c/KWH</b>		
2	1.049	
3	1.068	
4	1.087	1.9c/gal per 1c/KWH
5	1.106	
6	1.125	
7	1.144	
<b>% of Capital</b>		
110	1.075	
100	1.106	3.0c/gal per 10%increase
90	1.136	



## CHAPTER 4. CORN GRIT TECHNOLOGY

### CORN GRIT PROCESS FLOWSHEETS AND DESCRIPTIONS

The process flowsheets are the same in all sections as in the base case process except for Section 500 - Distillation and Dehydration. The modified Section 500 flowsheet is given in Drawing 345411-18. This process arrangement is based on our best judgement of what is needed to operate the plant after visit ADM and reviewing the literature on corn grit dehydration.

Whereas in the base case the beer still overhead at about 93 wt% ethanol is dehydrated in a heat coupled solvent distillation column with solvent recovery columns, the corn grit dehydration system is conceptually simpler. Since the beer still is no longer heat integrated with the dehydration columns, the beer still can operate at atmospheric pressure. Thus, the beer still TA-514 is slightly lower in capital cost for the same throughput compared to the base case. In order to preheat the beer from the fermentor, a spiral heat exchanger, EN-502, is used in true counter current flow with the hot still bottoms. The spiral heat exchanger is well suited for the slurry nature of the beer and bottoms. The reboiler EA-511 has the same duty as in the base case, but is rated for lower pressure, using 50 to 25 psi steam instead of 150 psi steam. The usual side stream loop for fusel oil recovery is given in T-538.

The lights are withdrawn as before from the top of the beer stills. The condenser, EN-503, provides the reflux to the column. Near the top of the beer still a vapor stream at 92 to 93 wt% ethanol is withdrawn and heated to 200°F for passage through packed bed (PT-501) filled with corn grits. The details of the arrangement of the packed beds and the process parameters are proprietary information of the ADM Corporation. They allowed us to visit the plant and gave us enough information to estimate the capital equipment and energy requirements.

The concept of the corn grit dehydration is given in U.S. Patent No. 4,345,973 by Michael R. Ladisch and George T. Tsao. The rights are assigned to ADM Corporation of Decatur, Illinois. Other published references are given at the end of this section.

There are a number of packed beds in PT-501 and some are in service removing water vapor from the ethanol vapor, while others are in the generation phase. The hot dehydrated ethanol vapor leaves the packed bed and is cooled in EN-508 and condensed in EN-509 as 199 proof ethanol. For those beds which are switched into the regeneration stage, hot CO<sub>2</sub> is circulated through a loop. It is heated in EN-508 and EN-507. A blower is used to circulate the gas. When the wet CO<sub>2</sub> leaves the bed, it is cooled in EN-505 and the water is condensed in EN-506. The CO<sub>2</sub> is separated from the water in the knock drum DN-502 and continues around the loop. The corn grit has proven very reliable and lasts for years in the packed beds. The entire cost of corn grits in the system is less than \$20,000.

The steam requirement for the corn grit technology is the same as the base case since all the turbine and thermal loads are the same. The electrical load is 6972 KW due to the addition of a blower/compressor for the CO<sub>2</sub> recirculation loop in the dehydration process.



The dehydration of ethanol with corn grit adsorbent can also be applied to the Biostil process for an additional savings in capital investment.

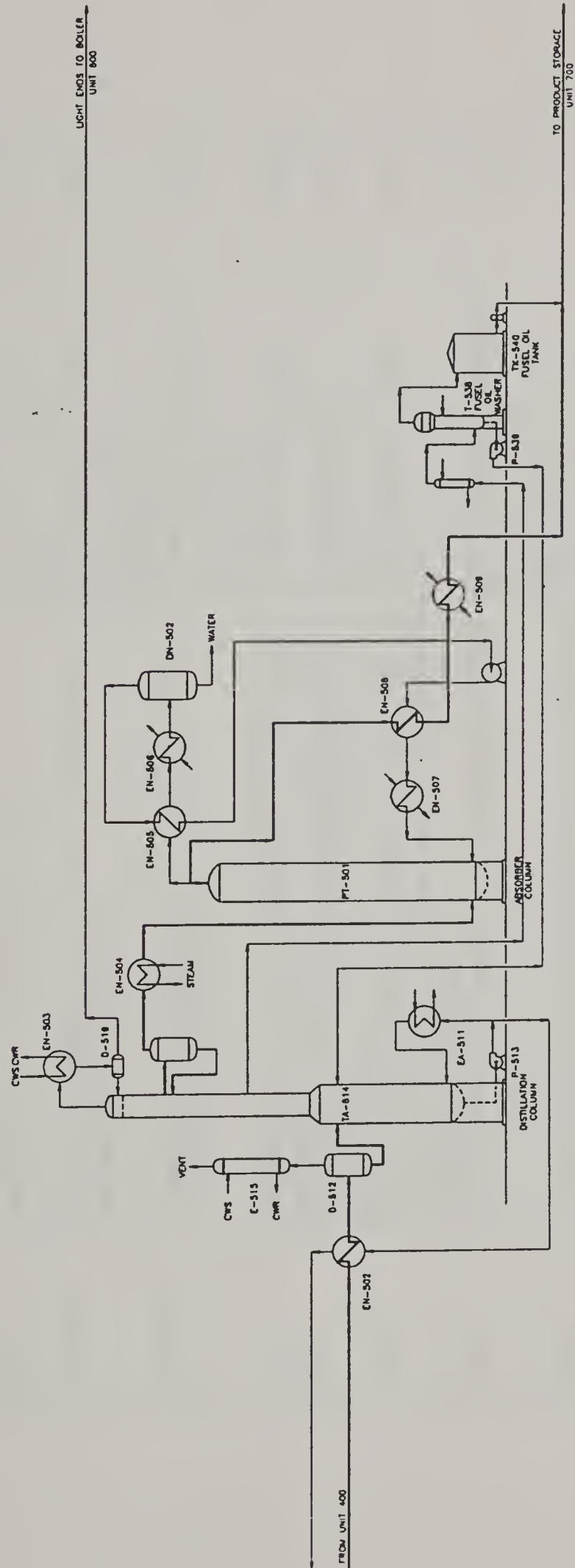
As before, the fixed capital for the plant is developed from the delivered cost of equipment of each section. Only Section 500 is changed in this alternative in Table 20. The other section costs are as in the base case as seen in Table 21, where the total fixed capital is \$113,600,000.

The operating costs, given in Table 22 are essential the same as in the base case except for capital related charges which are lower and electricity which is slightly higher.

#### References on the Corn Grit Dehydration

1. Ladisch, M. R., M. Voloch, J. Hong, P. Bienkowski, and G. T. Tsao. Cornmeal Absorber for Dehydrating Ethanol Vapors. *Ind. Eng. Chem. Process Des. Dev.*, 1984, 23, 937-943.
2. Hong, J., M. Voloch, M. R. Ladisch, and G. T. Tsao. Adsorption of Ethanol-Water Mixtures by Biomass Materials. *Biotechnology and Bioengineering*, 1982, 24, 725-730.
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4. Lee, J. Y., P. J. Westgate, and M. R. Ladisch. Water and Ethanol Sorption Phenomena on Starch. *AICh Jr.*, 1991, 37, No. 8, 1187-1195.
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6. Bienkowski, P. R., A. Barthe, M. Voloch, R. N. Neuman, and M. R. Ladisch. Breakthrough Behavior of 17.5 mol % Water in Methanol, Ethanol, Isopropanol and t-butanol Vapors Passed Over Corn Grits. *Biotechnology and Bioengineering*, 1986, 28, 960-964.





SECTION 500 - DISTILLATION AND DEHYDRATION FOR CORN CRIB

DATE	7/1/82	DATE	7/1/82	DATE	7/1/82
ENGR BY		ENGR BY		ENGR BY	
PROJECT NO.	34-3411	PROJECT NO.	34-3411	PROJECT NO.	34-3411
SHEET NO.	34-3411-18	SHEET NO.	34-3411-18	SHEET NO.	34-3411-18
					
Michigan Engineering & Construction					



**TABLE 20. Equipment List for Corn Grit Technology**  
Section 500 - Distillation and Dehydration

	Description	Design Conditions	Materials of Construction	Estimated Cost (1992)
P-501	whole stillage pump, centrifugal, 1,200 gpm, 100 ft TDH, 50 hp	40 psig, 250°F	316 SS	\$7,300
EN-501 A/B/C/D	bottoms cooler/feed preheater, total Q=55.4 Mbtu/hr, four units required with A=3,000 ft² each	25 psig, 220° F, spiral 58" dia x 96"	304 SS	\$420,000
EN-502	feed heater, Q= 4.71 M btu/hr, A = 300 ft²	25 psig, 220 °, spiral	304 SS	\$10,500
EN-503 A/B	ethanol relex condenser, total Q = 75.2 M btu/hr, two units required with A = 4,400 ft² each	tubes - 25 psig, 220° F / shell - 50 psig, 250° F	304 SS/CS	\$310,000
EA-511 A/B	stripper/rectifier reboiler, total Q = 94.4 M btu/hr, two units required with A = 3,350 ft² each	tubes - 25 psig, 220° F / shell - 50 psig, 250° F	304 SS/C.S.	\$206,600
D-512	degasser drum, 5 ft dia x 6 ft high, ASME F&D heads, top and bottom	100 psig, 350°F	304 SS	\$19,360
P-513	dehydration column reboiler pump, centrifugal, 3,500 gpm, 30 ft TDH, 50 hp	75 psig, 350°F	D.I.	\$5,800
TA-514	stripper/rectifier - 2 sections: bottom section - stripping-138 in dia, 87 disc and donut trans; top section - rectification-102 in dia, 28 perforated trays	75 psig, 325°F	304 SS	\$752,620
E-515	degassing vent condenser, Q = 500,000 btu/hr, A = 100 ft²	tubes - 25 psig, 220° F / shell - 50 psig, 250° F	304 SS / C.S.	\$8,300
P-518	rectifier reflux pump, centrifugal, 650 gpm, 170 ft TDH, 40 hp	110 psig, 275°F	304 SS	\$5,600
D-519	rectifier reflux drum, 6 ft dia x 5 ft high, dished heads	25 psig, 200°F	304 SS	\$15,180
E-537	fusel oil cooler, A = 50 ft²	tubes - 25 psig, 220° F / shell - 50 psig, 250° F	304 SS / C.S.	\$4,950



TABLE 20. Equipment List for Corn Grit Technology  
Section 500 - Distillation and Dehydration

	Description	Design Conditions	Materials of Construction	Estimated Cost (1992)
T-538	fusel oil washer, 24 in dia x 15 ft high, w/36 in dia x 24 in settling drum, skirt bottom	25 psig, 200°F	304 SS	\$8,030
P-539	wash water pump, centrifugal, 30 gpm, 115 ft TDH, 1 hp	150°F	D.I.	\$1,500
TK-540	fusel oil storage tank, nom cap = 5,000 gal, cone roof, flat bottom	atm., 150°F	C.S.	\$8,250
P-541	fusel oil pump, metering, 10 gpm, 150 ft TDH	150°F	D.I.	\$800
EN-504	ethanol vapor heater, Q = 580,000 btu/hr, A = 144 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$2,880
EN508	ethanol/ CO2 exchanger, Q = 1.72 M btu/hr, A = 884 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$17,700
EN-507	CO2 heater, Q = 2.06 M btu/hr, A = 450 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$9,000
EN-509	ethanol vapor condenser, Q = 16.2 M btu/hr, A = 3200 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$64,000
EN-505	CO2/water vapor cooler, Q = 940,000 btu/hr, A = 150 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$3,000
EN-506	water condenser, Q = 8.6 M btu/hr, A = 3255 ft <sup>2</sup>	plate- 50 psig, 250° F	316 SS	\$65,100
C-501	CO2 compressor and motor	5 psig delta inlet 50° F	CS	\$64,000
DN-503	ethanol condensate drum, 6 ft dia x 5 ft high, dished heads	25 psig, 200° F	CS	\$6,940
DN-502	water condensate drum, 6 ft dia x 5 ft high, dished heads	25 psig, 200° F	304 SS	\$15,300
PT-501-508	packed bed tower with corn grits	25 psig, 250° F	CS	\$216,000
	Total Equipment, Unit 500			\$2,248,710



<p align="center"><b>TABLE 21</b>  <b>Fixed Capital Cost Estimate for 50 Million Gallons Per Year</b>  <b>Fuel Grade Ethanol from Corn Corn Grit Technology</b></p>				
<b>Section 100 - Grain Storage and Handling</b>				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,628,008
2	Installed equipment cost	1	1.43	\$2,328,052
3	Process piping	2	0.07	\$162,964
4	Instrumentation	2	0.05	\$116,403
5	Buildings and site development	2	0.10	\$232,805
6	Auxiliaries	2	0.25	\$582,013
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,422,236
9	Engineering and construction	8	0.20	\$684,447
10	Contingencies	8	0.10	\$342,224
11	Size factor	8	0.02	\$68,445
12	Total fixed capital investment			\$4,517,352
<b>Section 200 - Cooking and Saccharification</b>				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,438,578
2	Installed equipment cost	1	1.43	\$2,057,167
3	Process piping	2	0.30	\$617,150
4	Instrumentation	2	0.10	\$205,717
5	Buildings and site development	2	0.20	\$411,433
6	Auxiliaries	2	0.25	\$514,292
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,805,758
9	Engineering and construction	8	0.20	\$761,152
10	Contingencies	8	0.10	\$380,576
11	Size factor	8	0.02	\$76,115
12	Total fixed capital investment			\$5,023,601
<b>Section 400 - Fermentation</b>				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$5,345,699
2	Installed equipment cost	1	1.43	\$7,644,349
3	Process piping	2	0.50	\$3,822,175
4	Instrumentation	2	0.05	\$382,217
5	Buildings and site development	2	0.10	\$764,435
6	Auxiliaries	2	0.25	\$1,911,087
7	Other	2	0.00	\$0
8	Total physical plant costs			\$14,524,263
9	Engineering and construction	8	0.20	\$2,904,853
10	Contingencies	8	0.10	\$1,452,426
11	Size factor	8	0.02	\$290,485
12	Total fixed capital investment			\$19,172,027



**TABLE 21**  
**Fixed Capital Cost Estimate for 50 Million Gallons Per Year**  
**Fuel Grade Ethanol from Corn Corn Grit Technology**

Section 500 - Distillation				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$2,248,710
2	Installed equipment cost	1	1.43	\$3,215,655
3	Process piping	2	0.60	\$1,929,393
4	Instrumentation	2	0.20	\$643,131
5	Buildings and site development	2	0.10	\$321,566
6	Auxiliaries	2	0.25	\$803,914
7	Other	2	0.00	\$0
8	Total physical plant costs			\$6,913,659
9	Engineering and construction	8	0.20	\$1,382,732
10	Contingencies	8	0.10	\$691,366
11	Size factor	8	0.02	\$138,273
12	Total fixed capital investment			\$9,126,030
Section 600 - Feed Processing				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$10,110,379
2	Installed equipment cost	1	1.43	\$14,457,842
3	Process piping	2	0.50	\$7,228,921
4	Instrumentation	2	0.10	\$1,445,784
5	Buildings and site development	2	0.10	\$1,445,784
6	Auxiliaries	2	0.25	\$3,614,460
7	Other	2	0.00	\$0
8	Total physical plant costs			\$28,192,792
9	Engineering and construction	8	0.20	\$5,638,558
10	Contingencies	8	0.10	\$2,819,279
11	Size factor	8	0.02	\$563,856
12	Total fixed capital investment			\$37,214,485
Section 700 - Storage and Shipping				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$1,541,062
2	Installed equipment cost	1	1.43	\$2,203,719
3	Process piping	2	0.30	\$661,116
4	Instrumentation	2	0.05	\$110,186
5	Buildings and site development	2	0.10	\$220,372
6	Auxiliaries	2	0.25	\$550,930
7	Other	2	0.00	\$0
8	Total physical plant costs			\$3,746,322
9	Engineering and construction	8	0.20	\$749,264
10	Contingencies	8	0.10	\$374,632
11	Size factor	8	0.02	\$74,926
12	Total fixed capital investment			\$4,945,145



TABLE 21				
Fixed Capital Cost Estimate for 50 Million Gallons Per Year				
Fuel Grade Ethanol from Corn Corn Grit Technology				
Section 800-A - Boiler Related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$6,876,347
2	Installed equipment cost	1	1.00	\$6,876,347
3	Process piping	2	0.25	\$1,719,087
4	Instrumentation	2	0.10	\$687,635
5	Buildings and site development	2	0.20	\$1,375,269
6	Auxiliaries	2	0.25	\$1,719,087
7	Other	2	0.00	\$0
8	Total physical plant costs			\$12,377,425
9	Engineering and construction	8	0.20	\$2,475,485
10	Contingencies	8	0.10	\$1,237,742
11	Size factor	8	0.02	\$247,548
12	Total fixed capital investment			\$16,338,201
Section 800-B - Non-Boiler Related Utilities				
Item	Description	% of Item #	Chilton Factor	Cost
1	Delivered equipment cost	1	1.00	\$7,273,059
2	Installed equipment cost	1	1.00	\$7,273,059
3	Process piping	2	0.25	\$1,818,265
4	Instrumentation	2	0.10	\$727,306
5	Buildings and site development	2	0.20	\$1,454,612
6	Auxiliaries	2	0.25	\$1,818,265
7	Other	2	0.00	\$0
8	Total physical plant costs			\$13,091,507
9	Engineering and construction	8	0.20	\$2,618,301
10	Contingencies	8	0.10	\$1,309,151
11	Size factor	8	0.02	\$261,830
12	Total fixed capital investment			\$17,280,789
	Total fixed capital for Sections 800-A and 800-B			\$33,618,990
	Total			\$113,617,630



TABLE 22. Operating Cost  
 Corn Based Ethanol Plant in Illinois, 1992  
 50 Million Gallons Per Year, 199° (99.5 wt %)  
 330 Operating Days Per Year  
 Corn Grit Technology - batch fermentation, distillation, dehydration with corn grits,  
 thin stillage evaporation and DDGS drying

Item	Annual Use	Units	Value Per	Unit	Annual Cost	Cost/Gal	% of Total
<b>A. MATERIALS</b>							
1. Corn, 56 lb/bu	1088	M lb/y	\$2.50	/bu	\$48,571,429	0.971	62.26%
2. Yeast	792	K lb/y	\$0.40	/lb	\$316,800	0.006	0.41%
3. Gasoline denaturant	285120	gal/y	\$0.60	/gal	\$171,072	0.003	0.22%
4. Ammonia	6.075	M lb/y	\$120.00	/ton	\$364,500	0.007	0.47%
5. Lime	1.584	M lb/y	\$40.00	/ton	\$31,680	0.001	0.04%
6. Sludge polymer	16	K lb/y	\$3.00	/lb	\$48,000	0.001	0.06%
7. BFW Chemicals	40	Klb/y	\$1.00	/lb	\$40,000	0.001	0.05%
8. NaCl	792	Klb/y	\$50.00	/ton	\$19,800	0.000	0.03%
9. enzymes	155000	gal/y	\$7.77	/gal	\$1,204,350	0.024	1.54%
<b>B. LABOR</b>							
1. operators	43	people	\$40,000	/y	\$1,720,000	0.034	2.20%
2. labors	54	people	\$25,000	/y	\$1,350,000	0.027	1.73%
3. technicians	8	people	\$35,000	/y	\$280,000	0.006	0.36%
4. maintenance	25	people	\$40,000	/y	\$1,000,000	0.020	1.28%
5. fringe benefit	25	%			\$1,087,500	0.022	1.39%
<b>C. ENERGY</b>							
1. Illinois #6 Coal	195.8	M lb/y	\$25.00	/ton	\$2,447,500	0.049	3.14%
2. Electricity	55,218,240	KWH/y	\$0.05	/KWH	\$2,760,912	0.055	3.54%
<b>D. CAPITAL</b>							
	Total Investment		% of Capital				
1. investment charges	\$113,617,630		11.11		\$12,622,919	0.252	16.18%
2. insurance			1.00		\$1,136,176	0.023	1.46%
3. maintenance			2.50		\$2,840,441	0.057	3.64%
							0.00%
<b>E. TOTAL</b>					\$78,013,078	1.560	100.00%
<b>F. CREDITS</b>							
	Annual Product		Value Per	Unit			
1. ddgs	346.8	M lb/y	\$120	/ton	\$20,808,000	0.416	26.67%
<b>G. NET COST</b>							
					\$57,205,078	1.144	73.33%



TABLE 23. Operating Sensitivity  
Corn Grit Technology

Price Change in Item	Net Production Cost, \$/gal	Change in Net Production Cost per Indicated Price Change
Electricity,c/KWH		
2	1.111	
3	1.122	
4	1.133	1.1c/gal per 1c/KWH
5	1.144	
6	1.155	
7	1.166	



## CHAPTER 5. ENERGY CONSIDERATIONS

In the base case the fixed capital associated with the high pressure, coal fired boiler is \$16,300,000 out of a total investment of \$118,000 or 14% of the capital. Coal contributes 4.9¢/gal or 3.12% of the operating cost. In addition, the operating cost contributed by the capital charges is 34.5¢/gal. If we take 14% of 34.5¢/gal or 4.8¢/gal plus the 4.9¢/gal for fuel, we see about 10¢/gal influence due to the need for steam generation. In a lesser way the electricity use adds another 5.2¢/gal. Thus, an important area in the design of an ethanol plant is to take advantage of fuel cost differentials and capital cost trade-offs. These have big leverages and are site specific and are as significant as any process technology options in the fermentation distillation or drying.

For example, on a btu basis, coal is cheaper than natural gas or oil. Generally, high sulfur coal is cheaper than low sulfur coal. All of these fuels are cheaper per btu than purchased electricity. While there are many alternatives to consider, they are beyond the scope of this study. Just to give the flavor of the opportunities we point out some extremes.

The use of a cogeneration steam/electric power plant is most appealing. Here the thermodynamic efficiency is maximized since shaft work is extracted in the turbine and the exhaust steam is used for its heating values. If you size the turbine to just produce the required exhaust steam, then you set the work load of the turbine. In the base case it is fortunate that the turbine work matches the compressor load for the evaporator. If you desire to produce more shaft work, the steam flow must increase. If the steam is not needed for process heat, you need to supply a cool tower as in a conventional electric power plant. It is possible to locate an ethanol plant in an industrial complex with other steam and power users so that the cogeneration plant has the largest economy of scale. For example, ADM in Decatur, Illinois, has a cogeneration power plant producing 150 mega watts of electricity and 2.6 million pounds of steam per hour which services the corn wet mill, fructose production, ethanol production, soy bean processing, hydroponic green house and other adjacent clients. Thus, the cost of energy for steam and electric are as low as you can get.

Moreover, this power plant uses fluidized bed coal combustion furnaces and this allows the introduction of lime with the coal to capture the sulfur in the combustion chamber as  $\text{CaSO}_4$ . This is a cheaper sulfur control strategy than adding a flue gas scrubber to a conventional coal fired boiler. Also, a fluidized bed boiler can burn other solid waste fuels. For example, ADM shreds used tires and mixes them with the ground coal to be about 10% of the fuel by weight. The tires are brought to the plant and ADM charges a fee of \$20/ton for disposal. The fee covers the cost of shredding the tires and provides for a reduction in the net fuel cost.

In the base case, the fixed investment for a conventional coal fired boiler and related equipment is \$16,300,000. If this were replaced by a fluidized bed boiler of the same capacity, the fixed cost would be about \$22,600,000. To justify this higher investment, one needs to realize about a \$5/ton (23.5¢/Mbtu) savings in the coal cost. At the present time in Illinois, the cost of low sulfur Wyoming coal is \$1.15 per million btu whereas the high sulfur coal from



Illinois is \$1.30/Mbtu. This is due to over supply of Western coal. Thus, the negotiation of long term coal contracts are an important factor in deciding the type of boiler. The availability of local wastes of reasonable btu value will provide further leverage on fuel costs.

On the other extreme is to simplify the boiler as much as possible as in the Biostil case so low pressure steam is adequate. This leads to packaged boilers which reduce the capital charges significantly. Now we are in a period of relatively low energy costs and the use of natural gas at \$1.50/Mbtu is hard to beat. For example, coal at \$25/ton with a heat value of 10,630 btu/lb is equivalent to \$1.18/Mbtu. Switching to natural gas would increase the fuel cost for the base case plant by \$683,000 per year. A savings of fixed capital in the boiler by over \$6,100,000 is needed to justify using natural gas.

In some areas the cost of electricity may be lower than the typical 4.5 to 5¢/kwh. In this case, one can consider driving the compressors in evaporator by an electric motor and replacing the high pressure boiler with a packaged low pressure boiler.

The development of vapor recompression in the ethanol distillation deserves some further development as in the corn grit case since the beer still is operated by itself at atmospheric pressure. About half the steam load can be saved by recompressing the overhead ethanol vapors for the still reboiler heating media.

Finally, the use of gas turbines with a waste heat boiler offers another way to get both motive power and steam heating at relatively small compact sizes to match a stand alone plant energy requirement.



## CHAPTER 6. FUTURE DEVELOPMENTS

The maximum yield of ethanol from starch in corn can be calculated from a typical analysis of corn at 61.0% starch in an "as is" kernel with 16% moisture. From a 56 lb bushel there is 34.16 lb starch or 37.5 lb of glucose when fully hydrolyzed. The maximum ethanol is 19.2 lb or 2.89 gal/bushel. The typical plant today achieves a yield of 2.55 gal/bu which is 88% of theory. Some plants report 91% yield. Naturally, the plant should be operated to get as high a yield as possible since the corn cost is the major cost.

There is the potential to get more ethanol from the fiber in the corn kernel. In a USDA work shop in Peoria, July 91, it was pointed out that the cellulosic fiber in corn is about 11%. If we could hydrolyze all the fiber in the cellulose and hemicellulose and convert the hexose and pentose sugars into ethanol, it is possible to get another 0.3 gal per bushel of corn. From the sensitivity Table 11, it is clear that the corn cost can be reduced by 10.8¢/gal at most. This savings in raw material per gal of product has to pay for the added capital, energy, material and labor costs to convert the fiber to ethanol.

In the Biostil process no yield improvement was assumed over the base case. However, the continuous fermentation with a steady 6 to 7 wt% ethanol in the broth can lead to small yield improvements. Since the yeast is recycled, less carbon of the substrate goes in yeast propagation. Also the glycerol level is lower in the steady state environment where the yeast is under less metabolic stress. Thus, carbon not converted to glycerol is available to become alcohol.

The stillage drying in the base case uses a rotary drum type drier heated with hot flue gas. Weatherly, Inc. recommends using a flash drier which is lower in capital than the rotary drier, but uses about 10 to 15% more energy. When energy is cheap as it is now, this may be a good trade-off. The other main advantage of the flash drier is the low drying time and low temperature, which ensures a high quality, light colored DDGS. A careful study of the DDGS drying performance of different drying processes which are optimized with respect to production cost is a fruitful area of development.

Membrane technology has been evolving and with each advance new applications become cost effective. The removal of ethanol from the fermentor broth in some type of recirculation loop is appealing from a conceptual point of view. Continuous fermentation with continuous ethanol removal will allow rapid uninhibited fermentation - similar to the Biostil process. In discussions with Dr. Eric Lee at Sepracor Inc., Marlborough, Massachusetts, we became aware of a pervaporation membrane system designed to remove alcohol from wine. The cost for going from 11% to 0.5% ethanol is roughly \$1 per gallon treated. The key development here is to prevent water and flavor components from coming through the membrane is a pervaporation system. A small membrane cutoff prevents flavor components from passing through the membrane. Water vapor is used in the sweep gas on the exit side of the membrane to neutralize the driving force for the water transport.



In a fermentor producing fuel ethanol, the flavor issue is irrelevant. Also, the ethanol level need only be reduced in the fermentor to 5%, not 0.5%. With these changes, there is the expectation that a membrane that can be more productive and hopefully cost effective than in wine dealcoholization. The membrane can be made more porous to allow higher fluxes (perhaps 5 times higher) and pass flavor components (fusel oils). Also, the cost roughly doubles for each halving of the ethanol concentration. Where all this will end up in cost is hard to say, but there are some significant cost reductions possible. Naturally, development work on the specific problems is needed to push this technology to the limit. Since pervaporation is a surface area phenomenon, the scale-up will be linear and so it will have some difficulty at very large scales to be economic if it is economic at a smaller scale. The key point is that pervaporation does not have to do the whole job of purifying ethanol, but make an enrichment that can be interfaced with distillation so there is an overall cost saving.

The dehydration of ethanol after the beer still with molecular sieves has been a technology that is used in plants below 20,000,000 gallons per year capacity. It appears that molecular sieves are used in beds that are limited to 12 ft height to control pressure drop and 4 ft diameter to control channeling. Consequently, the scale-up is essentially linear for large plants and so there is no economy of scale. However, some designs are being built by Vogelbusch for 30 to 40 million gal/y.

Based on the comments by David Penner at Universal Oil Products, Des Plaines, Illinois, he sees no limit on the scale-up of molecular sieve beds. UOP has proprietary designs for large beds which have been demonstrated in hydrogen drying. The same principles can be applied to ethanol dehydration.

Although the process design is proprietary to UOP, the concept is to use a series of beds with molecular sieves. Some beds are in service dehydrating ethanol vapor, at a slightly elevated pressure and the other beds are in the regeneration phase at sub atmospheric pressure. This is the so called pressure swing cycle. No heating of the beds is necessary to regenerate them. While the molecular sieve costs about \$1.20/lb, their operating life is indefinite if properly used. The fixed capital cost estimate for the dehydration via molecular sieves is similar to the corn grits process.

A rather mundane item to consider in an ethanol plant is the selection of heat exchangers used in condensers, heaters, coolers and reboilers. In Section 500 of the base case, the delivered cost of heat exchanger is about \$1.5 million out of \$3.34 million (see Table 5). By the time this equipment is installed the cost is about 4.1 times higher than the delivered cost. The standard heat exchangers are shell and tube type. In recent years more and more use of plate heat exchangers and spiral heat exchanger has occurred because for equal duty they are cheaper than shell and tube type heat exchangers.

According to John Corcoran of Alfa-Laval Thermal Division, Richmond, Virginia, the cost of plate heat exchangers in 316 SS are \$20/ft<sup>2</sup> from 300 ft<sup>2</sup> to 2000 ft<sup>2</sup>. With a wide gap spacing as used in reboiler the cost is \$30/ft<sup>2</sup>. Moreover they have between 4 to 5 times the heat transfer coefficient of a shell and tube unit. Thus, you can design for a closer approach on the



differential temperature and get a greater percentage of the energy available for exchange. From Figure 1, the cost curves for shell and tube and plate show that the costs are less for the plate heat exchanger. In effect you can use less ft<sup>2</sup> of heat exchanger surface for a given duty.

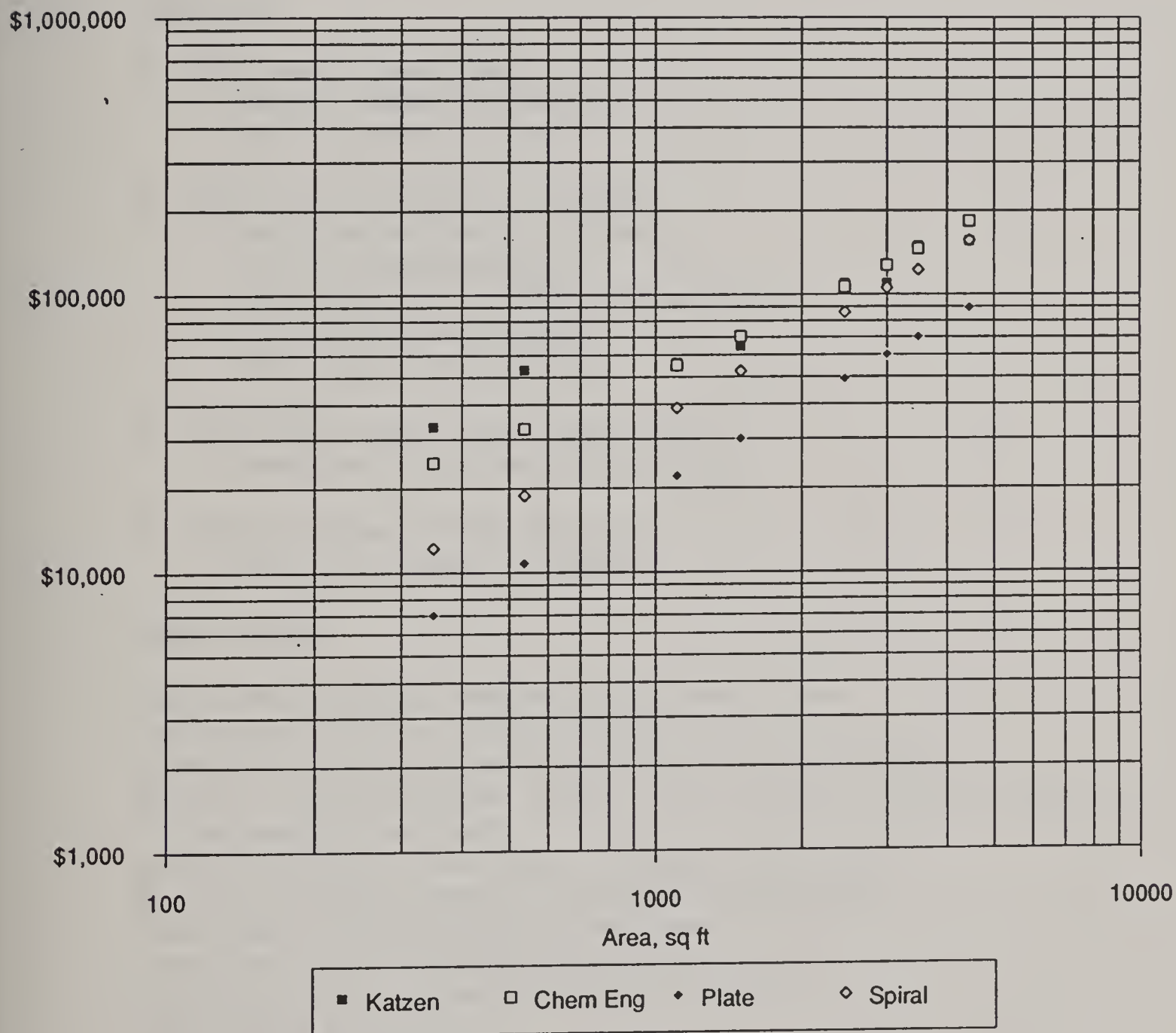
In the case of spiral heat exchangers the cost is more like \$35/ft<sup>2</sup> for sizes of 500 ft<sup>2</sup> to 2000 ft<sup>2</sup>. These costs are more than the cost for plates but less than shell and tubes. Spirals are especially useful for slurries as in the still bottoms and fermentor broth. The heat transfer coefficient for spiral units are greater than for shell and tube units but less than for plate unit.

With the reduced cost per square foot and higher coefficients, the capital investment in heat exchanger can be reduced. For example, in Section 500, a heavy use of heat exchangers, the delivered cost for heat exchangers of all types comes to about \$1.6 million out of a total for the section of \$3,340,000. A savings of \$500,000 to \$800,000 is possible in converting all the shell and tube heat exchangers in the section. By the time you look at the impact on the fixed capital for heat exchangers, this cost reduction is multiplied by about 4.

Why are these not used more widely? It is a question of demonstrating the claimed performance in an ethanol plant. Some reports by Katzen say plate exchangers plug-up. Perhaps spirals should have been used. In any case, the wider use of plate and spiral heat exchangers should be promoted through demonstrations and user groups. The use of plate as well as spiral heat exchangers also offers easy access for cleaning with corresponding labor savings.



FIGURE 1. Heat Exchanger Purchase Cost in 1992  
 Shell and Tube Type with Floating Head and 304SS Tubes  
 from Katzen plant design and Chemical Engineering cost correlation, Jan. 25, 1982.  
 Plate Heat Exchanger and Spiral Heat Exchanger Costs from Alfa-Laval





## CHAPTER 7. ACKNOWLEDGEMENTS

The authors wish to acknowledge the help by a number of people at different organizations in providing technical information and validating key points about ethanol production, utilities and energy costs, during our visits to their plants or by extended telephone interviews.

### Plant Visits

1. Perkin Energy, Perkin, Illinois  
Ronald H. Miller, V.P. Marketing  
Gary Welch, Chief Chemist
2. Archer Daniel Midland, Decatur, Illinois  
Martin Andreas, Corp. V.P. Marketing  
John Long, Director of R&D  
Ed Harjehausen, V.P. Marketing Ethanol Group  
Robert Meyers, Chief Operator  
Terry Wells, Purchasing Agent
3. New Energy Company, South Bend, Indiana  
Larry Russo, Project Development Manager
4. South Point Ethanol, South Point, Ohio  
Barry Cohen, Director of Operations

### Phone Interviews

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Marlborough, Massachusetts  
Jerry Osborn, Tempella Power Corp., Williamsport, Pennsylvania  
Eugene Tis, Tempella Power Corp., Williamsport, Pennsylvania  
Mike Burger, ABB, New Brunswick, New Jersey  
George Joniec, Process Alternatives, Lambertville, Michigan  
Phil Dimitry, Black and Veatch, Ann Arbor, Michigan  
Ghulam Haider Illinois Power  
Bruce Sandlin, Illinois Power  
Michael Ladisch, Purdue University, W. Lafayette, Indiana  
John Nystrom, Arthur D. Little, Cambridge, Massachusetts  
Douglas McDonald, Michigan State University, Simon's Power Plant, E. Lansing,  
Michigan



John Corcoran, Alfa-Laval Thermal Division, Richmond, Virginia  
David Penner, Universal Oil Products, Division of Union Carbide, DePlaines, Illinois  
John Wallish, Dean Boiler, Grand Rapids, Michigan  
James C. Craig, Jr. Research Leader, Engineering Science Research Unit, USDA, Eastern  
Regional Research Center, Philadelphia, Pennsylvania.

Special thanks to the following people for providing a significant amount of data and process information:

Raphael Katzen (Raphael Katzen Associates International, Cincinnati, Ohio) for his detail base case design and discussions.  
Magnus Daniellson, Sales and Marketing Engineer; Victor Hudon, Project Manager; and David Boyd, Manager of Sales and Marketing (Weatherly, Inc., Atlanta, Georgia) for their information on the Biostil process.



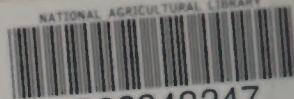
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